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REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1939–40.*

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BY

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ABSTRACT.

The Report summarizes the work of the Bartol Research Foundation over the period April 19, 1939 to April 17, 1940; and in the Appendix it lists:

1. The titles of the papers which have been published and which have actually appeared,
2. The papers presented at various scientific meetings,
3. Addresses presented before various institutions, all of these applying to the aforesaid period.

The Report itself commences with a statement on the relation between investigations in pure science and those of an immediately utilitarian nature. Next are described several investigations having to do with *electrical discharges in gases*, particularly in relation to the operation of *Geiger-Mueller counters*. These investigations include studies by W. E. Ramsey of the *variation of the discharge with time* and of the *occurrence of and conditions for multiple discharge*. The facts are harmonized into a consistent *theory of Geiger counter discharge* by a theory developed by C. G. and D. D. Montgomery. Further investigations by W. E. Ramsey concern the part played by *ultraviolet light in the discharge of a Geiger counter*. Studies by S. A. Korff concerning the use which may be made of Geiger counters for *discriminating between different kinds of particles* are described. The *time lags* between the passage of a ray through a Geiger counter and the initiation of the discharge form the subject of an investigation by C. G. and D. D. Montgomery. A *modification of Geiger counter design*, due to S. A. Korff and W. E.

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* Presented at the Stated Meeting held on April 17, 1940.

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Ramsey, made with a view to the utilization of large counter areas with a minimum of operating voltage is described.

Next comes an experimental investigation by W. F. G. Swann and Wayne Lees designed to verify a theory of the former concerned with the *deviation of cosmic rays in passing through magnetized iron. An experimental investigation* of this deviation is also being carried out by I. O. Myers, using the cloud chamber technique. These investigations are examples of the use of cosmic rays as tools for the study of matters concerned primarily with the nature of the magnetic field in magnetized substances.

By an apparatus involving a large number of Geiger counters in conjunction with electroscopes, W. F. G. Swann and W. E. Ramsey have investigated many phenomena concerned with cosmic-ray showers produced by cosmic-ray mesotrons. These investigations are described. They include a *verification of the quantum theory of shower production* by mesotrons for the case of lead, a study of the *variation of this shower production with atomic number*, and the provision of *evidence for the existence of showers of mesotrons.* Examples are cited of *very dense showers* recorded by the apparatus. Results on a comparison of the *absorption coefficients of lead and tin* for mesotrons are given as obtained with the foregoing apparatus, and results on a comparison of the *absorption coefficients of lead and water* for mesotrons are cited as obtained by M. A. Pomerantz with another form of apparatus.

A large cloud chamber devised by T. H. Johnson, J. G. Barry and R. P. Shutt for the *investigation of the properties of mesotrons* is described, and several pictures taken with it are shown. The cloud chamber is capable of accommodating a lead block 5 cms. thick in addition to two lead slabs, each 1 cm. thick.

A theoretical investigation by C. G. and D. D. Montgomery is described and has for its purpose the establishment of the conclusion that all the *large cosmic-ray showers produced in the atmosphere* can be accounted for as originating from electrons produced therein or coming in from the outside.

A further investigation by the Montgomerys arrives at a law for the *energy distribution of electrons coming into our atmosphere with energies far above the range in which the paths of the particles are affected appreciably by the earth's magnetic field.* The results in question are reached by a study of the densities of the rays in the large showers observed at sea-level.

Experiments on the variation of neutron intensity with altitude, and made by S. A. Korff using the radio-balloon technique, are described, as are also experiments by Korff leading to conclusions as to the *intimate association between neutrons and large showers observed in the atmosphere.* A theoretical investigation by S. A. Korff, in collaboration with H. A. Bethe and G. Plazcek, is described, the purpose of the investigation being to trace the *life history of a cosmic-ray neutron in our atmosphere* with the ultimate purpose of providing the proper interpretation of measurements concerned with cosmic-ray neutrons in relation to the actual number of neutrons involved.

Measurements by Mr. Eric T. Clarke of the *latitude variation of cosmic-ray intensity*, made on the recent Byrd Antarctic Expedition, are described and the results are recorded.

Last year T. H. Johnson and J. G. Barry made an investigation which showed that in very high altitudes in equatorial regions the cosmic-ray intensity varies sufficiently little with azimuth to invite the belief that the number of electrons of both signs entering the atmosphere were approximately equal. To *free these results from suspicion of ambiguity resulting from scattering of electrons* in the upper atmosphere, Johnson and Barry have performed an experiment using the radio-balloon technique with the purpose of testing for any uncertainty of the kind cited. The result has been to confirm the former conclusions.

The Report concludes with the state of progress of *development of the new Van de Graaff Generator* in construction in the laboratory under the immediate supervision of W. E. Danforth and with the generous coöperation of Dr. R. J. Van de Graaff and Dr. J. G. Trump of the Massachusetts Institute of Technology, who have provided invaluable advice with regard to the machine.

While by no means all of our activities are devoted to the investigation of cosmic rays, a large proportion of our effort has been aimed in that direction during the last few years. Sometimes I am asked the question "What is the use of studying cosmic rays?" The fact that anyone would ask this question usually implies that he would not be satisfied with an answer based upon the mere search for knowledge for its own sake. He requires a more utilitarian reason. And so I usually answer this question by asking another: What is the use of a microscope in medicine and surgery? With a microscope one cannot cure a disease or mend a bone. No, but with a microscope we can learn much concerning bacteriology, which has a very fundamental bearing upon the cure of disease and upon the technique of surgery. And so, in the cosmic rays we are presented with activities bound up in most rich and fundamental degree with the fundamentals of the structure of atoms and molecules. Science has reached a stage in which it has exhausted in large degree the potentialities for progress inherent in a general empirical knowledge of the properties of matter. We have reached a stage in which the questions which remain to be answered dig down to the fundamentals of atomic structure; and if ever we are to realize in practical degree such dreams as the utilization of atomic energy, it will be through the aid of greater knowledge acquired by the study of such phenomena as those met with in the cosmic rays that we shall realize success.

It is a strange fact that nearly all achievements in the utilitarian realm of the progress of our civilization have come from researches commenced, in the first instance, with no utilitarian end in view. We owe our metallic filament lamps, our radio tubes which have rendered possible all forms of wireless communication, sound recording, trans-continental telephony, and a hundred other less obvious services, to researches undertaken in the spirit of pure curiosity. We owe these things to the development of highly efficient vacuum pumps, stimulated by researches on the mechanism of the conduction of electricity in gases. We owe them in part to the discovery, about 30 years ago, of facts concerned with the emission of electricity from hot bodies, facts whose investigation at the time seemed to have no purpose other than the satisfaction of the curiosity of the investigators and the enhancement of their reputations. We owe to purely academic researches into the nature of the conduction of electricity in gases all such devices as neon lights and the like, so prominent today in advertising and in the general field of illumination. X-rays, which serve a fundamental purpose, not only in surgery, but also in analysis of the structure of metals, we owe to an accident followed by investigations whose starting point was a search for the cause of the accident. Radioactivity, which revealed itself as an apparent triviality, from the utilitarian standpoint, in spite of its obviously fundamental role in the realm of pure knowledge, soon paid ample reward to man for his labors in its investigation by the use which has been found for it in the treatment of disease.

When the atom smashers, by the invention of methods of endowing atomic particles with high energy, had achieved a means of successfully bombarding the atomic nucleus, it seemed as though research had left the practical domain for ever unless by chance it could realize some day that dream of the alchemist, the transmutation of the elements. However, hardly had the atomic bombardment commenced with the full force of the modern artillery than the creation of artificial radioactivity was achieved, and with it the provision of a whole array of new substances capable of producing the same therapeutic effects as radium, but with widely enhanced elasticity in their use.

And so one might go on almost endlessly citing the achievements which pure science has claimed for the benefits of utilitarianism. I admit that the physicist does not, as a rule, investigate fundamental matters with a utilitarian aim in view. Indeed, our experiences of the past show us that if he ever had aimed at a rich utilitarian duck the chances are that he would have missed him and shot an equally utilitarian pheasant. No, it has to be confessed that the man of science investigates because he likes investigating, and somehow or other, nature, conscious of his laziness when engaged in something in which he is not interested, has contrived that the discoveries which advance civilization shall have as their forerunners dainty tidbits calculated to excite his mental palate. Perhaps after all this is a general principle in the running of the universe, for are not the flowers made beautiful and filled with honey, that the bees in search of the pleasures of these beauties may perform the greater service to the world in the cross-fertilization of the plants.

INVESTIGATIONS CONCERNING THE PROPERTIES OF GEIGER-MUELLER COUNTERS.

Experimental Phenomena.—The first investigations which I shall describe are not concerned primarily with cosmic-ray phenomena, although the appliance to which they refer—the Geiger-Mueller counter—has played a very important role in cosmic-ray investigations, as indeed it has in many investigations in other fields. The field to which the investigations to be described apply is that of the mechanism of conduction of electricity in gases, the field whose initial study by J. J. Thomson and his collaborators gave us the electron, the proton, and practically all the fundamental bases for the discoveries in twentieth century physics.

Frequently in these reports I have had occasion to refer to the Geiger-Mueller counter, and it will be necessary again to remind you that it consists primarily of the following parts: The essentials are a thin tungsten wire, surrounded by a metal cylinder, the whole being enclosed in a glass tube, which can be evacuated and filled with suitable gas to the appropriate pressure—say, 9 cms. of mercury. If the wire is given a positive potential V in relation to the wire, then if V is sufficiently large, but of course, below the value necessary for spontaneous discharge, the passage of an ionizing ray through the tube will precipitate a discharge which, under proper conditions, is roughly instantaneous; and the electric charge transferred in the discharge may, by suitable amplifying devices, be caused to record in any fashion desired.[1]

Now, so useful have these Geiger counters become in many branches of physics, that their design and methods of construction have been dictated rather with a view to their immediate use in some scientific investigation than with the object of thoroughly understanding what happens in their operation. As a consequence, a good deal of rule of thumb procedure, and Chinese medicine, has been associated with their construction. People have been accustomed to speak of "good counters" and "bad counters," and all sorts of tricks and devices have been used and suggested for producing "good counters." Different kinds of gases have been used, and sometimes they have been subjected to rather mysterious treatment, as, for example, that of causing them to pass over a piece of iodine, or some other substance, during their transmission to the counter tube. Indeed, I was once tempted to suggest that the presence of the traditional rabbit's foot during the filling of a counter might have some beneficial effect.

Now, as the progress of research has advanced, it has become necessary to demand more and more exactness and reproducibility in the operation of these counters, so that the time has come when a more thorough understanding of their operation is essential, and the ability to control that operation in a known and dependable manner has become imperative.

An elementary but incomplete story of the action of the Geiger counter may be told by a reference to Fig. 1, in which, with a counter subjected to a constant intensity of ionizing rays from outside, we have plotted vertically the number of rays recorded per unit of time by the counter, and horizontally the positive potential of the wire, with the potential of the cylinder taken as an arbitrary zero. Starting from zero with increasing potential, no rays are recorded until a point, roughly designated by *A*, and called the "starting potential," is reached. Then the counting rate rises, roughly instantaneously, to a value determined by the line *BC*, which remains constant until the potential of the wire has risen to a value at which spontaneous discharge occurs, after which further increase of the potential results in a very rapid rise in the counting rate to a condition in which the discharge becomes continuous.

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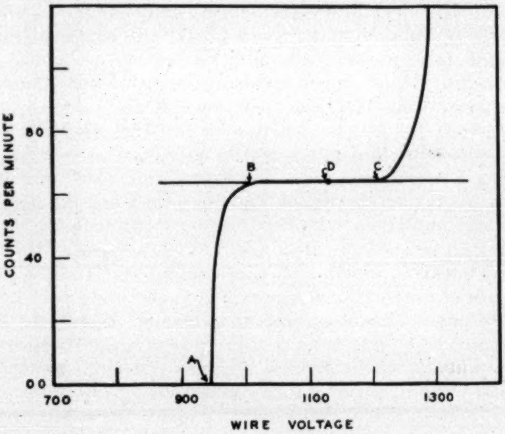
[1] At this point, a simple form of counter was demonstrated by its action in counting the rays which passed through it. These rays were of cosmic-ray origin and of radioactive origin depending upon the existence of radioactive substances in the atmosphere. The action of an artificial radioactive source was also demonstrated. Different forms of counters were shown, including thin-wall counters suitable for detecting beta-rays of low penetrating power, and these were demonstrated.

FIG. 1.



According to the simplest, but necessarily incomplete and even erroneous, view of the operation of a counter in the region *BC*, we may picture an action such as the following: Starting with the counter wire at a potential such as that corresponding to *D*, an ionizing ray passes through the counter. This generates a few pairs of ions, any one of which is sufficient for our discussion. The potential of the point *D* must be presumed to be sufficiently high to cause these ions to produce others by collision. Since most of the potential drop is in the vicinity of the wire, it will be this region which is primarily affected in giving rise to a large number of ions by the collision process, and it matters little whether the original pair of ions was generated near to or far from the wire, the path of their activity in initiating the ionization by collision process is that which they experience just before they reach the wire. It is for this reason, moreover, that the starting potential *A* is a more or less well-defined potential, independent of where any particular ray happens to produce a pair of ions in the tube. Following the elementary picture, we may suppose this discharge to continue, with the result that, if the wire is insulated, it will fall in potential, becoming nearer to the potential of the cylinder. When it has fallen to the value determined by the starting potential *A*, ionization by collision ceases, and the discharge stops. If, as is the case in practice, the wire is not strictly insulated, but is connected to a point at the original potential *D* through a high resistance, this resistance plays practically no part in preventing the wire from falling down to the starting potential practically instantaneously and so annulling the discharge, although it does, subsequently, play an important role in bringing the wire back relatively slowly to the initial potential corresponding to the point *D*.

According to the foregoing simple view, therefore, every ionizing ray precipitates a situation in which the counter wire falls from its intitial arbitrarily assigned potential to a potential equal to that of the starting potential. The pulse available for amplification depends, of course, upon this fall of potential and so upon the intitial potential symbolized by *D*. If we should subject the potential of the wire to an analysis, as regards its time variations, by an oscillograph,[2] we should expect to obtain some such curve as that shown in Fig. 2, in which the wire, starting from its initial potential symbolized by *OA*, falls to a value *OB* equal to the starting potential. If the oscillograph were capable of recording on one picture a slow process as well as a rapid process, we should see the curve, after reaching the point *B*, rise slowly until it had attained an ordinate equal to *OA*.

Now in practice we find that the foregoing naïve picture is not true to the facts, and the facts represent two distinct types of cases which have been elucidated experimentally by

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[2] For our purpose, an oscillograph may be regarded as an apparatus which produces a photographable—and, of course, observable—curve whose horizontal axis is time and vertical axis wire potential.

FIG. 2.

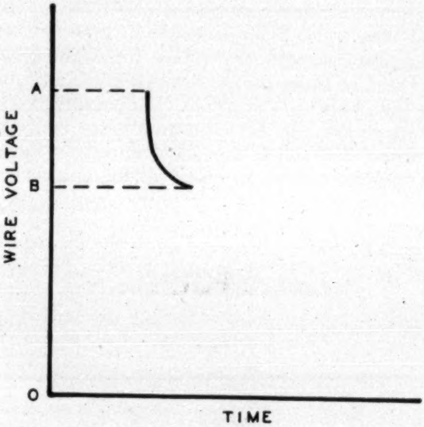
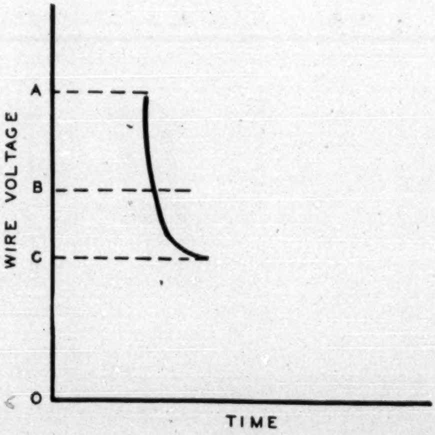


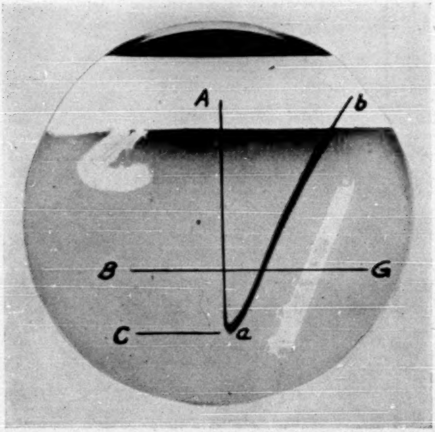
FIG. 3.



Mr. W. E. Ramsey,[3] and which have received a theoretical interpretation, to which I shall presently refer, in the hands of Dr. and Mrs. C. G. Montgomery.

The simplest case occurring in practice, which we shall call a case of the first class, is that indicated in Fig. 3, which is similar to Fig. 2 above, except that the potential of the wire actually falls during the discharge to a value which is below the magnitude *OB*, which we have defined as the starting potential. Figure 4 shows an actual photograph of the oscillograph record for a counter wire discharging in this manner. Starting at the point *A*, the wire potential has fallen [4] to the point *C* which is below the starting potential roughly represented by the line *BG*. The portion of the photograph represented by *ab* happens, in this case, not to be representative of the counter recovery through the high resistance but of a more rapid recovery initiated arbitrarily in the circuits con-

FIG. 4.



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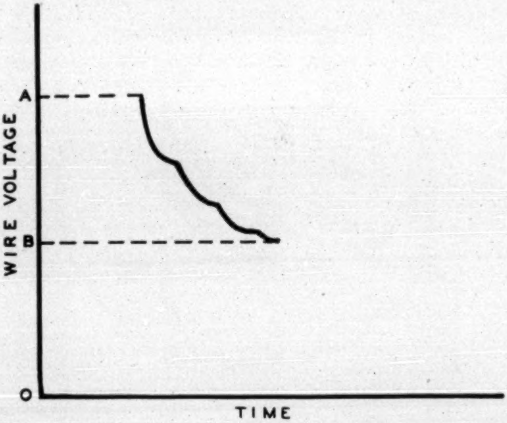
[3] W. E. Ramsey, in preparation for publication.

[4] In view of the rapidity of the discharge, it has been necessary to touch up the photograph for reproductional purposes.

cerned for the purpose of facilitating the operation of the oscillograph recordings.

The second case realized in practice, which we shall call a case of the second class, is that represented in Fig. 5, in which

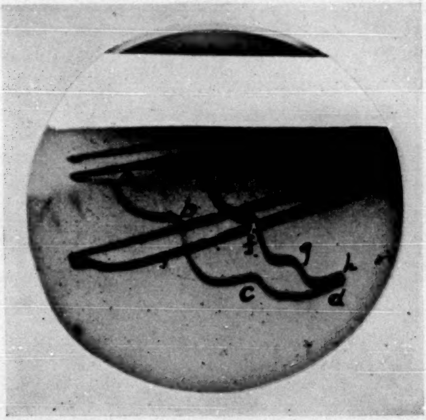
FIG. 5.



the wire potential falls to a kind of preliminary equilibrium point which is well above the starting potential, after which it experiences another similar fall to another temporary equilibrium point, the process being repeated theoretically, as it turns out, indefinitely, none of the temporary equilibrium points nor the final real equilibrium point ever falling below the starting potential. Figure 6 represents a photograph obtained by Mr. Ramsey and exhibiting two examples of this phenomenon in the portions *ab*, *bc*, *cd*, and the portions *ef*, *fg*, *gh*. The remainder of the marks on the photograph are irrelevant to the discussion.

It is essential to notice that in all cases of the first class the counter wire during the discharge overshoots the starting potential—a circumstance difficult to understand on what I have called the naïve theory—while in all cases of the second class, the counter wire falls to points of temporary equilibrium and ultimately to a minimum potential, all of these potentials being above the defined starting potential. The naïve theory gives no reason for the stepwise character of the discharge, nor indeed for the realization of a final potential which is above that of the starting potential.

Fig. 6.



Theoretical Considerations.—The foregoing phenomena, and certain others, are very beautifully explained by a theory developed by Dr. and Mrs. C. G. Montgomery.[5] This theory depends upon the realization of the fact that the observed change of potential of the wire during the discharge does not result in an appreciable amount from the negative charge which goes on to it, but from the movement of the positive charge away from it. The situation is, in fact, as follows: After the original ionizing ray has performed its act of producing at least one pair of ions in the counter, the negative ion, in accordance with the elementary considerations already given, moves towards the wire, but only in the immediate vicinity of the wire where the electric field is large does it succeed in promoting copious ionization by collision. At this stage we, therefore, have a number of positive and negative ions close to the wire and approximately randomly distributed. Even though the original ion which precipitated the situation has given its charge to the wire, this charge is so small that the wire experiences no appreciable change of potential on account of it. It is the subsequent history of affairs which tells the important story and in this history the first thing that happens is that the negative ions which are near to the wire give up their charge to it. Strange as it may seem, this causes very little change of potential of the wire because those negative ions were almost on the wire before, and it is easy to show that the act of actually going on produces no appreciable effect. The important thing is that the positive ions move away from the wire under the influence of the field, and in doing so, they act inductively upon the wire in such a way as to decrease its potential, the decrease continuing until the positive ions have reached the cylinder wall.[6] The question of

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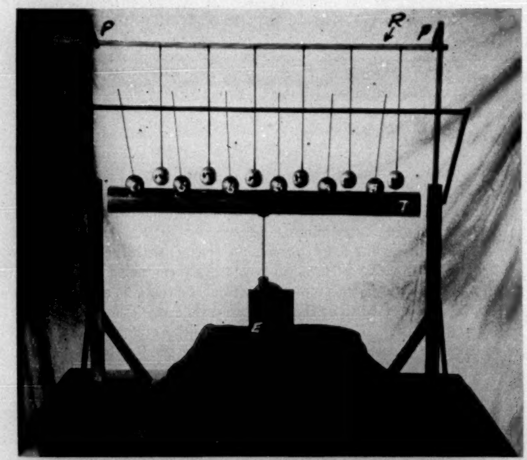
[5] C. G. and D. D. Montgomery, *Phys. Rev.*, 57, 1030 (1940).

FIG. 7.



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[6] At this stage, the discussion was illustrated by an experiment which constituted a kind of model of the actual process. A long metal tube, *T*, Fig. 7, was

whether this inductive action will lower the potential of the wire to the starting potential is one which involves considerations depending upon the original difference of potential between the wire and cylinder, which difference of potential determines the change in potential which the wire must experience to reach the starting potential.[7] If the inductive change of potential takes the wire below starting potential, nothing further can happen, even if the arrival of the positive ions at the cylinder should release negative ions therefrom,[8] for such negative ions, in traveling to the wire, would not acquire enough energy to initiate ionization by collision. In this case, therefore, we have the simple case shown by Mr. Ramsey's photographs, Fig. 4, and corresponding to what I have called the case of the first class.

Suppose now that the conditions should be such that the inductive change of potential resulting from the motion of the positive ions is so little that, on the arrival of these ions at the cylinder, the wire has not fallen as far as the starting potential. Then, if the positive ions should release electrons from the cylinder—and they can do so by parting with the energy which they possess in virtue of their charged condition—these released electrons will travel towards the wire and

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connected to an electroscope, *E*, and near it were placed an equal number of black balls, *B*, and white balls, *W*, the black balls being charged positively and the white balls to an equal extent negatively. The black balls were supported on a number of thin parallel rods on which they could slide, and from which they were insulated. The rods were supported on a yoke, which could be rotated so that they could be inclined to any extent. The white balls were supported by insulating silk threads from a rod, *R*, which itself was supported by elastic, *PP*, so that on placing a weight on the rod, *R*, the white balls could be brought into contact with the tube, *T*. It was observed that very little motion of the leaf was caused by allowing the white balls to come into contact with the tube. However, by starting with the rods horizontal and rotating them to an inclined position, the black balls could be made to move away from the tube, *T*, and when this was done, a much larger deflection of the electroscope leaf was obtained.

In order to work with the electroscope in a condition of convenient sensitivity, its case was kept at a potential finitely different from the "zero" potential of the apparatus, and the electroscope itself was mounted in a lantern not shown in the figure.

[7] These matters were illustrated by means of the experiment described under footnote 6.

[8] Which, in fact, they probably do, as I shall presently find occasion to emphasize in connection with the Montgomery theory of the multiplicative discharge.

under conditions in which the field, while less than it was in the intitial discharge, is nevertheless still sufficient to initiate ionization by collisions. Under these conditions, we may get a complete repetition of the first phenomenon, with a second migration of positive ions outwards from the wire to the cylinder, and a second fall of potential of the wire. If this second fall has still not brought the wire to the starting potential, and indeed the theoretical considerations show that it would not, then the whole process will be repeated once more. Indeed, a full consideration of all the elements involved shows that the process will be repeated theoretically an indefinite number of times, but with smaller and smaller changes of potential on each occasion, until finally the limit of the starting potential is reached.

As part of the working out of the theory which I have already discussed, certain other important considerations came to light.

Suppose that, starting from the instant when the act of copious ionization by collision has been consummated, we plot the change of potential of the wire against the time. Then the theory of Dr. and Mrs. Montgomery leads to an expression of the type [9]

$$V - V_0 = C \log (t/t_0 + 1), \qquad (1)$$

where V_0 is the initial potential of the wire. Here C is a constant depending upon the dimensions of the counter, the capacity of the wire system, the pressure and nature of the gas, and the initial difference of potential between the wire and the cylinder. The quantity t_0 also depends upon the counter conditions and determines the rapidity of change of the potential.

Now, equation (1) is exactly of the type found by Mr. Ramsey [10] for the relation between the potential of the counter wire and the time. The essential feature, namely, the proportionality between $V - V_0$ and $\log(t/t_0 + 1)$ is borne out by Fig. 8, representative of Mr. Ramsey's data, and showing

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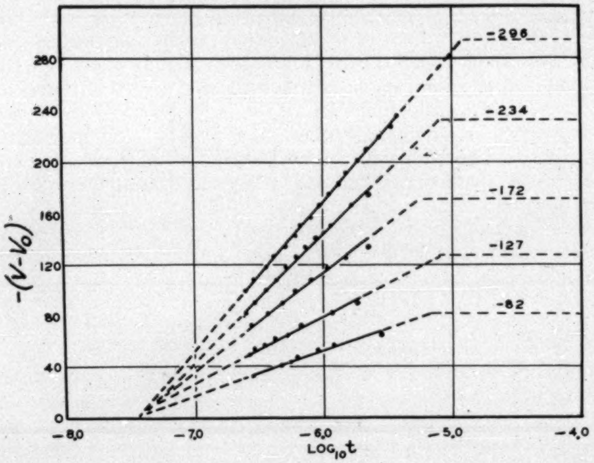
[9] The equation only has an approximate significance in the vicinity of $t = 0$, at which instant the movement of the positive ions and the production of ions are not yet disentangled.

[10] W. E. Ramsey, *Phys. Rev.*, **57**, 1022 (1940). It is hardly necessary to describe here the details of Mr. Ramsey's experiments, which are described in full in the publication listed above. It will suffice to say that the general principle is as follows: The electrical circuit used has characteristics the equivalent of that of a switch which permits a fixed current of electricity to flow into a standard

FIG. 8.



The graphs here shown correspond to different values of V_0. The horizontal portions labelled with numbers represent, by those numbers, the maximum values of $-(V - V_0)$. The remaining dotted portions of the graphs are obtained by extrapolation, since they correspond to regions of difficulty for experimental measurement. Curves similar to the above were also obtained for different capacities associated with the wire.

that with the value $t_0 = 3.5 \times 10^{-8}$ second, which in fact the experiments determine, the linear relationship in question holds.

As an interesting example of the interplay of theory and experiment, it may be remarked that the foregoing matters were not elucidated in the order in which I have presented them. The starting point was the experiments of Mr. Ramsey last described, leading to the results indicated in Fig. 8.

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condenser from the instant when the wire potential commences to change until the instant when it has attained a predetermined value which may be varied in different observations. The quantity of electricity which flows into the condenser in the aforesaid time becomes a measure of that time, and so of the time for the wire to acquire the predetermined potential aforesaid.

It was in attempting to explain these results that the Montgomerys were led to develop their theory. However, the theory did not stop at giving a reason for Mr. Ramsey's results, but predicted as further consequences the likelihood of there being two distinct types of counter discharge such as represented our first subject of discussion in connection with what I have called counter discharges of the first and second classes. It was as a result of these predictions of the theory of Dr. and Mrs. Montgomery, that Mr. Ramsey was stimulated to look for these interesting types of discharge by the utilization of the oscillograph and found the phenomena already described.[11] I may say that one of the chief points of importance in these investigations of Mr. Ramsey and the Montgomerys lies in the fact that they show these phenomena of multiple discharge and those concerned with overshooting to be phenomena normally inherent in the working of a Geiger counter. In the past, when there has been any suspicion of such phenomena, there has been a tendency to regard the counter as defective and to expect that a counter which is working properly should always behave according to what I have called the elementary but incomplete theory of operation.

Further Investigations Concerning Geiger Counters.—There is a further matter which invites question in relation to the foregoing discussion regarding the operation of counters. In that discussion, we have pictured ionization by collision as being initiated in the vicinity of the wire by an electron originally ejected by the incoming radiation. The description of events so far given provides no immediate reason for the spreading of the discharge beyond the planes perpendicular to the wire, in which the ionization by collision originated. However, there is evidence to the effect that once the Geiger counter has commenced to discharge, the discharge perpetuates itself more or less immediately throughout the whole length of the counter and the mechanism of this perpetuation has been the subject of study by Mr. W. E. Ramsey.

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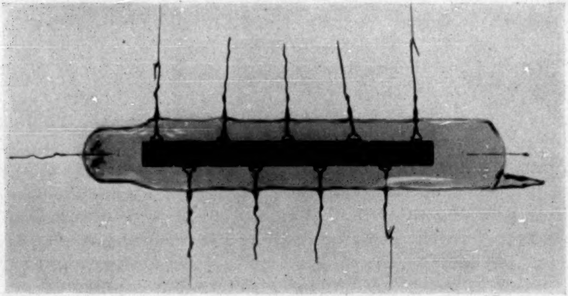
[11] For the interest of those who are specialists in this field and who, aware of the frequent use of oscillographs in the past in analyzing Geiger counter phenomena, are at a loss to understand why the features of multiple discharge, etc., observed by Mr. Ramsey, have not been recorded before, it may be remarked that in order to cause the phenomena to reveal themselves in a dominating form, free from suspicion as to their being of accidental nature, it is necessary to use a circuit which suppresses the importance of the first member of the multiple series.

Mr. Ramsey caused to be constructed a counter, of the type represented in Fig. 9, in which the cylinder was made of a number of independent segments insulated from one another. If the wire of the counter be kept at a fixed potential during operation, then the movement of the positive ion sheath, referred to earlier, necessitates the supply of a pulse of electricity to the cylinder if its potential also is to be kept constant. It is easy to measure this pulse by arrangements which it is unnecessary now to describe. If the discharge of the counter were confined to a single plane perpendicular to the axis, then it would only be the segment of the cylinder containing that plane which would receive an appreciable pulse of electricity. However, Mr. Ramsey finds that the passage of a single ray through the Geiger counter causes all segments of the cylinder to become operative. Moreover, *when the operating potential difference for the counter is small*, there are time lags of the order of 10^{-4} second between the instants of operation of any two segments if intermediary segments are prevented from operating by the use of small potential differences between them and the wire. These phenomena suggest that the discharge initiated at one point perpetuates itself to other points through the act of some agency which, traveling from the first point,

FIG. 9.



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possesses the power to initiate directly or indirectly ionization by collisions at the other points. Mr. Ramsey has sought to determine whether the transmitter of the contagion is a charged particle, and to this end he has caused the counter to operate in a strong magnetic field perpendicular to its axis. Such a magnetic field would deviate the path of the charged particle, causing it to strike the wall of the cylinder early in its journey and so prevent it from carrying the effect over the length of the tube. The magnetic field had no effect and the inference is that it is not a charged particle which is involved. One immediately thinks of transmission of the effect by ultraviolet light originating in the vicinity of the initial region of ionization, and striking the various cylinders with the emission from them of electrons which then serve as initiators of ionization by collisions in each of the various cylinder segments, with a resulting spread of the discharge throughout the whole counter tube. The difficulty attending this view lies in the fact that the ultraviolet light transmission would occur practically instantaneously, and there is no immediately obvious reason, therefore, for the time lags between the various segments. However, in spite of these considerations, it seems likely that the phenomenon must be attributed to ultraviolet light and that mechanism of the time lag is to be found in a procedure which Mr. Ramsey envisages as follows: Suppose a discharge is initiated at one point. Then, as is well known, the recombination of ions in the ionized gas gives rise to the emission of ultraviolet light in the form of photons. If the counter is operated at a low potential difference, the number of the photons emitted will be small. It is not certain that one of these photons, when striking the cylinder, will emit an electron therefrom. There is only a finite probability that this will occur, and only a finite chance that one of the segments other than that originally excited will have an electron emitted from its cylinder wall. However, small operating potential difference is the condition for multiple discharge. If the photons of the first discharge do not operate any assigned segment, the photons of a subsequent discharge may do so, and, between the successive discharges, there will be a time lag depending upon the time necessary for the collection of the positive ions. The experimental verification of the existence of these time lags thus substantiates the nature of the mechanism, and points the way to an understanding of the normal operation of a counter with an operating potential difference greater than the small values used in the foregoing experiments. With the larger potential difference, the emission of photons at even a single discharge is sufficient to excite the adjoining regions of the counter and these in turn excite the regions adjoining them, so that the discharge becomes perpetuated throughout the whole counter.

Mr. Ramsey has in progress other experiments for testing the transmission of discharge from one point of a counter to another, but the foregoing account will serve to indicate the nature of the problem and the general principles involved.

In line with the foregoing considerations, and indeed to the end of enhancing further the possibilities inherent in the Geiger counter, Dr. S. A. Korff[12] has carried out certain investigations which I shall now describe.

I have already implied that a Geiger counter does not operate in the ordinary sense when the difference in potential between wire and cylinder is less than the value defined by the starting potential. However, even for potential differences less than this critical amount, certain interesting phenomena can happen, phenomena which have a special significance in the case of radiation such as that of alpha particles, which produce along their path much more copious ionization than do electrons.

Thus suppose that, let us say, alpha particles are passing through the counter and that we operate it at a very low potential difference. Then, each ray gives rise to a certain spurt of ionization which is not further increased by ionization by collisions but which can be detected if our recording apparatus is of suitable type and sensitive enough. In this case, if the particles always traveled a fixed distance in the counter, we could say that spurts of ionization would be proportional to the ionization per centimeter of path of the ionizing entity, so that we could distinguish, for example, between alpha particles and protons by observing the ionization spurts and comparing them with their relative theoretical values. If we were concerned with radiations from an external source, however, the comparison would be complicated by the fact that individual rays of the same kind would show a distribution of pulse sizes on account of the fact that all did not travel the same distance in the counter tube. However, there is a case of very great importance in which one is relieved of this ambiguity. It is a case where the ionizing particles are formed inside the counter tube itself as a result, for example, of artificial radioactive disintegration in the gas, and in which their range is so short that they complete that range within the counter tube. In this case, therefore, to which, as a matter of fact, we shall confine ourselves in the further discussion, we realize a condition in which, for low potentials, the spurts of ionization are proportional to the total ionizations produced by a particle in the whole length of its range.

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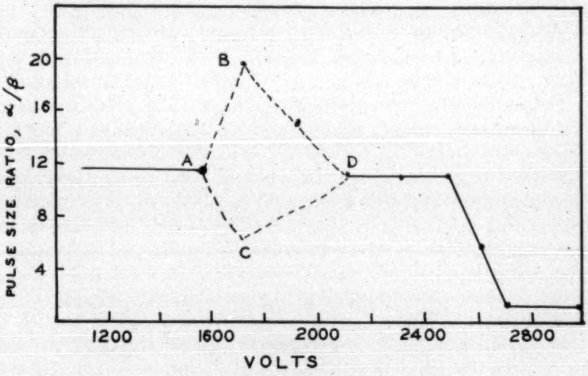
[12] S. A. Korff, *Phys. Rev.*, to appear shortly.

Suppose now that we increase the potential difference to a point at which ionization by collision can just occur, but not to a point so high that ultraviolet light emission can occur and propagate the discharge throughout the tube. Then, each ion generated by the ionization agency can serve as a separate source of ionization by collision, and so these ions will contribute additive pulses. It can be shown that when the potential is only just sufficient to promote ionization by collision, it will not always result in pulses of equal size even for equal initial spurts of ionization. This follows from the statistics of the problem combined with the Montgomery theory of counter quenching following a single discharge. There will be, in fact, a small range of potential in which proportionality between the recorded complex pulse and the number of original primary ions does not hold. As the potential is increased further, however, the measured pulse will be accurately proportional to the number of primary ions produced by the ionizing entity. This situation continues to prevail as the potential is still further increased, until finally we attain a potential at which the further complication of ultraviolet light emission occurs; we attain, in fact, what we have called the starting potential, and here the ultimate pulse, resulting as it does from the interchange of phenomena all over the tube, has no more relation to the ionization of the primary entity than has the size of a war precipitated by the murder of a few people to the number of people originally murdered. In this region of potential the counter simply counts numbers of rays and does not discriminate between them. This situation persists with increase of potential, until finally one reaches the potential of continuous discharge, after which all measurable phenomena have no relation either to the ionization produced by a single ray or to the number of rays.

In order to test the foregoing history of affairs, Dr. Korff has used as his primary ionizing agencies alpha particles and beta rays shot into the counter through a thin window from outside. The paths of the former within the tube, and so the ionization due to them could be made definite. While there is a technical uncertainty in the ionization produced by the beta rays depending upon the distance the particular ray travels in the tube, if we confine our attention to those cases where the entity in question ends its range within the tube, we have the theoretical and experimental guarantee that so much of the total ionization exists in a very small length near the end of the range on account of the large ionization per centimeter of path there, that any uncertainty in the actual length of path, involving as it does regions of small ionization per centimeter of path, is unimportant to a first approximation. Dr. Korff has, therefore, plotted Fig. 10, in which horizontally we have the potential difference between wire and cylinder, and vertically the ratios of the sizes of the pulses produced by the alpha rays to the maximum corresponding pulse sizes for the beta rays.

It will be seen that from zero potential up to nearly 1600 volts, the ratio in question is constant and equal to twelve, which is in close agreement with the theoretical value thirteen as applicable to alpha particles and beta rays. With increase of potential beyond 1600 volts, we find at first a condition in which successive observations even at the same voltage show wide variations within limits defined by the pentangular region, *ABDC*, indicated in Fig. 10. This is the region of uncertainty referred to in the description of the phenomena, and it exists up to a potential of 2100 volts. Further increase of potential again gives a constancy of the ratio at a value equal to that for the first part of the curve. When the potential has been raised to 2500, which is the starting potential for the counter used, the ratio of pulse sizes changes suddenly to unity in harmony with the fact already explained, that above the starting potential, the pulse size has no relation to the ionization characteristics of the primary entity.

FIG. 10.



Time Lags in the Initiation of Geiger Counter Discharge.—Our detailed discussion of Geiger counter action has so far been confined to the period subsequent to that at which ionization by collision has been completed, and the potential of the counter wire has started to rise. A naïve consideration of the situation would suggest that the period prior to this, namely, the period between the instant of passage of the original ionizing ray through the counter and the completion of ionization by collisions was practically infinitesimal and, in fact, of the order of magnitude of the time taken for an electron to travel through the gas for a distance comparable with the radius of the counter, a time less than 10^{-7} second. However, this view takes no account of any time consuming mechanisms which might be involved in the initiation of the ionization by collision, or in delay which the initially formed ions may experience in crossing the counter tube as a result of entanglement with gas molecules on the way.

Now evidence for time consuming effects of the foregoing kind first made their appearance last year in some experiments carried out by Dr. and Mrs. Montgomery in collaboration with Mr. W. E. Ramsey and Mr. D. B. Cowie [13] primarily for the purpose of determining the average life of that newly discovered particle, the mesotron. As part of this experiment, and the only part relevant to the present discussion, there were two counter systems, separated by about 10 cms. of air, and arranged so that, on the passage of a cosmic ray through both of them, they would only record if the pulses which their wires delivered to a certain vacuum tube were absolutely simultaneous. Now, if one uses this apparatus as it has been customary to use it, viz. as a cosmic-ray telescope, with the ordinary coincidence feature, and if, used in this way, it records cosmic rays, one has two possible views as to its action. According to the first, the observation of a ray means that there was no time delay in either counter, and according to the second, it means that there were time delays, but they were equal. According to previous views it would have been customary to believe that the first mechanism represented the facts. However, the experiment done in this way provides no discriminating information. Suppose, however, that we purposely introduce a time lag in the delivery of the pulse from one of the counter wires to the aforesaid vacuum tube, and find that under these conditions records are occasionally obtained. Then we know two things; first, that there have been occasions when there was a difference in time lag between the counters, and therefore, a finite time lag for at least one of them, and, second, that we have been successful in compensating that time lag by the lag artificially produced, as aforesaid. It will easily be seen that by making measurements of apparent cosmic-ray intensity with apparatus of the foregoing type and with different artificially created time lags, it was possible to demonstrate the reality of such time lags and to obtain some information as to their magnitudes. Thus, for example, it is reasonable to suppose that the maximum artificially produced time lag consistent with the realization of at least one record of a ray is of the order of the maximum time lag of one of the counters.

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[13] These experiments were described briefly in my last report, and in full in C. G. Montgomery, W. E. Ramsey, D. B. Cowie, and D. D. Montgomery, *Phys. Rev.*, **56**, 635 (1939).

It was by such experiments as the foregoing that Dr. and Mrs. Montgomery, Mr. W. E. Ramsey and Mr. Dean Cowie established the existence of these time lags, and Dr. and Mrs. Montgomery have shown that the maximum time lag is of the order of magnitude of the time taken by an ion, as distinct from an electron, to travel a distance comparable with the radius of the counter tube under the influence of the field. This caused them to lean to the view that these time lags were associated with the extent to which electrons originally freed by the cosmic rays traveled as electrons to the central wire, as compared with the extent to which they traveled in partnership with larger atomic entities.

While the time lags are too small to be of importance in the ordinary use of Geiger counters in coincidence arrangements, they have assumed a role of vital importance during the last few years in special problems which depend for their success upon adjustment of the apparatus so that absolute simultaneity of pulses from the counters becomes a necessary criterion for the securing of a record. Thus, for example, if one wishes to establish the exact simultaneity of emission of an electron and a gamma ray from a radioactive atom in some atomic disintegration, and if the experiment is arranged so that one of the counters records the electron while the other records the gamma ray, one becomes certain of the conclusion to be established just in proportion as he is certain of the simultaneity of operation of his counters, provided that the associated circuits are designed to demand simultaneity of operation to the desired extent in order that they shall secure a record.

Dr. and Mrs. Montgomery are continuing their investigations of time lags of counters by a process in which a single counter is operated by ultraviolet light from a spark, and the function of the other counter in giving an impulse is replaced by a direct electrical impulse from the spark itself, which impulse may be taken as instantaneous with the arrival of the ultraviolet light. The remainder of the procedure is similar to that used in former experiments, but by the device indicated one is able to deal with the time lags of a single counter as distinct from the difference between the time lags of two counters. A further advantage lies in the fact that the initially ejected electron responsible for the operation of the counter comes, in the case of the ultraviolet light, from a known place, the counter cylinder, rather than from some undefined point in the gas of the counter.

A Modification of Geiger Counter Design.—For some purposes, and particularly in the investigation of weak radiations, it is desirable to use a Geiger counter of large volume, and incidentally of large radius. However, the potential difference between wire and cylinder necessary to secure a large enough field in the vicinity of the wire becomes inconveniently great in the case of a counter of large diameter. For this reason, it has occurred to Mr. W. E. Ramsey to introduce a third element into the Geiger counter in the shape of a cylindrical wire grid concentric with the central wire. By setting up between this grid and the wire a potential difference which is not unduly high, one may realize, near the wire, a field sufficiently strong to initiate the process of ionization by collision. Then, one may use between this grid and the external cylinder a small potential difference which is no more than is necessary to guide through the grid those ions which are created in the external portion of the counter. By this process, the potential difference between external cylinder and wire can be utilized in the most economical manner in contrast to its utilization in a normal counter, where a large fraction of it is wasted in the regions far from the wire, where its only essential duty is to feed the wire region. Dr. S. A. Korff and Mr. W. E. Ramsey[14] have carried out tests with such counters and have found that the innovation constitutes a real improvement in those cases where there is a real reason for the use of large counter volumes. The details of operation of the device are a little more complicated than is suggested by the simple description which I have given, since the blocking effect of the grid itself for ions which seek to pass through it from the external volume is not limited to the mere mechanical interception of ions, but is modified by the attractive or repulsive action of the charge on the grid, which controls the flow of ions in a manner crudely analogous to that encountered in the case of the grid of a vacuum tube amplifier. However, the details of these matters are too involved for presentation here and must be left to the more complete publication covering the description and operation of these counters.[15]

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[14] S. A. Korff and W. E. Ramsey, *Rev. Scient. Instr.*, to appear shortly.

THE NATURE OF THE FIELD IN MAGNETIZED IRON.

The problem upon which I now wish to report is interesting in that, while effects on cosmic rays enter into its discussion, the problem is not one concerned primarily with the rays themselves. It is, in fact, a problem in which the cosmic rays may be used as tools to ascertain something about the nature of magnetic structure.

As soon as physicists realized that cosmic rays contained charged particles as part, at any rate, of their membership, the possibility of deviating the paths of these particles by causing them to pass through a magnetic field became immediately a subject of great interest. At this stage, unfortunately, it is necessary to become a little technical and to remind you that, in a crude way, we may regard a piece of magnetized iron as an assemblage of a very large number of magnets of molecular size which, in the absence of the state of magnetization of the iron, are arranged in all sorts of different directions but which become, partially at any rate, oriented in favor of one direction when the iron is magnetized. Modern physics does not regard these little molecular magnets as simple pairs of north and south poles, but as electrical entities. Thus, for example, a uniformly charged sphere when in rotation produces outside of itself a magnetic field which is exactly the same as that which would be produced by a very short magnet with north and south poles placed at its center, with the axis of the magnet parallel to the axis of rotation. Inside the rotating sphere, however, the magnetic field would be uniform in intensity and parallel to the axis of rotation if the sphere were charged only on the surface.

It will be realized that the actual field at a point inside a magnetized medium varies from point to point in a highly erratic manner. It has, however, an average direction and physicists have been accustomed to give the name "magnetic induction" to the volume average of the magnetic field in that direction, the volume average referring to a point in the sense that it is the average over a little volume, large compared with molecular dimensions but small in actual size, the little volume having its center at the point in question. This magnetic induction is a vector which is usually denoted by the symbol B. On the other hand, physicists have been accustomed to talk about another quantity—the magnetic field, h, at a point in the medium. By this they have not meant the true magnetic field whose average value is B, as aforesaid, but another quantity which has been defined in different equivalent ways. For our present purpose it will perhaps suffice to regard it as the true average magnetic field which we should experience in traveling along a length parallel to the general axis of magnetization, but being careful to keep always outside of the magnetic entities—the rotating spheres, for example—responsible for the magnetization. The ratio B/h is called the permeability of the magnetic substance, and it may have a very considerable value, a value as high as a thousand or more, for iron, although its value varies with the intensity of the magnetic field.

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[15] One of these counters was shown in the lecture.

Now the question which arose in connection with the deviation of cosmic rays through magnetized iron was whether B or h is the vector which should be concerned. A strict application of the recognized principles of electrodynamics to a model of the magnetized iron such as we have envisaged, a model in which the magnetic entities are electric currents of some form, would lead to the conclusion that B is the proper vector to choose. On the other hand, if there were in actuality such stuff as positive and negative magnetism (or, if we will, north polar and south polar magnetism) and if our magnetic entities were such as would be made by having a structure with positive magnetism on one end and negative magnetism on the other, then it turns out that h would be the vector appropriate to the magnetic problem.

Now experiments[16] on the deviation of cosmic rays by magnetized iron were not very concordant in their results, but corresponded, in general, to values intermediate between B and h. Some experiments by Dr. W. E. Danforth and myself, cited in one of my former reports, and published in full in the *Physical Review*[16] gave in one case a value lying between B and $B/2$, and in the other case a value lying between $3B/4$ and $B/4$.

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[16] B. Rossi, *Accad. Lincei, Atti.*, **11**, 478 (1930); L. M. Mott-Smith, *Phys. Rev.*, **39**, 403 (1932); B. Rossi, *Nature*, **128**, 300 (1931); L. Alvarez, *Phys. Rev.*, **45**, 225 (1934); W. F. G. Swann, JOUR. FRANK. INST., **222**, 647 (1936); W. E. Danforth and W. F. G. Swann, *Phys. Rev.*, **49**, 582 (1936).

In order to understand more thoroughly the nature of what is happining in a piece of magnetized iron, I worked out, a few years ago,[17] the special case where the magnetic entities are rotating uniformly charged spheres—the charge being on the surface—and compared it with the corresponding case for spheres of equal size with positive and negative magnetism distributed over the surfaces in such a manner that the external field due to one of these magnetized spheres, as we shall call them, was the same as that due to one of the rotating charged spheres. It turns out that such an adjustment of surface magnetic density is possible, and for this case, the portion of the field inside the sphere, due to the sphere, is exactly equal but opposite in direction to the corresponding field for the rotating charged sphere. In both cases the spheres were supposed to be fortuitously distributed, but their axes were all in the same direction.

A consideration of the foregoing problem led to some interesting conclusions, as follows: If by H we denote the true magnetic field at an absolute point inside or outside one of the magnetic entities, then

1. B is the average value of the true H in the vicinity of a point for the case of the rotating charged spheres.
2. h is the average value of the true H in the vicinity of a point for the case of the magnetized spheres.
3. The average value of the true H at a point when the averaging is confined to regions outside of the magnetic entities is [18] $h + 4\pi I/3$.
4. A cosmic ray passing through the magnetized iron would experience a deviation which was determined by B, provided that it traveled so far through the iron as to have passed through a sufficiently large number of

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[17] W. F. G. Swann, *Phys. Rev.*, **49**, 574 (1936).

[18] I is the intensity of magnetization, that is, the moment per unit volume.

magnetic entities (of the rotating charged type) to have experienced a true average as regards the field.

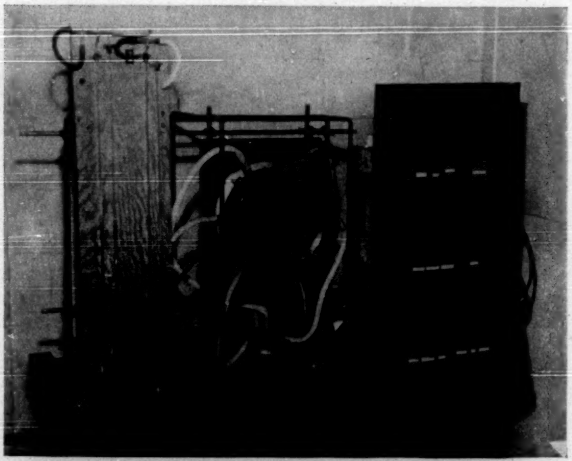
5. If, as would happen in general for the case of magnetic entities as small as classical electrons, for example, the the cosmic ray, in passing through the iron, did not pass through one single magnetic entity, then the effect of the deflecting field which it should experience is $B - 2\pi I$, or, what amounts to the same thing, $h + 2\pi I$.

To make the matter more intuitively understandable, I may say that it turns out that if the entity is very small, a cosmic ray passing through a slab of iron of reasonable thinness would rarely come into contact with or pass through such an entity as is pictured in (5). If it did, it would experience a very large deflection. It would be these very large deflections of cosmic rays, few in number, however, which would be responsible for making the true average deflection equal to that given by electromagnetic theory while the *practically measured* average was much less than this. The situation may be taken as analogous to the following. Suppose we have a country of a hundred million people, most of whom have on the average $1,000 a year. Suppose, however, a hundred of these people have a thousand million dollars per year. Then the true average income of an individual is approximately the one hundred thousand million dollars of the wealthy few plus the one hundred thousand million dollars of the majority of the people divided by the total number of people which is a hundred million. The average income is in fact $2,000. On the other hand, if I start checking up banking accounts at random, the chances that I encountered one of the very wealthy people would be extremely small and what I should practically find would be an average income of $1,000 a year. You will readily see that if I knew the number of the wealthy people, but did not know how much they had, and if I determined the difference between the practically measured average income and the true average income, I could determine something about the incomes of the wealthy people.

Since the effects to be obtained in deviating cosmic rays by magnetized iron depend so much upon the extent to which the rays actually succeed in passing near to or through the magnetic entities in traversing the piece of magnetized iron, it will be realized that valuable information concerning the size and nature of these entities should be obtainable by a study, not only of the average deviation of cosmic rays of assigned energy, but of the fraction of the rays deviated through ranges of angles other than the average angle of deviation. These matters are best studied in a cloud expansion chamber.

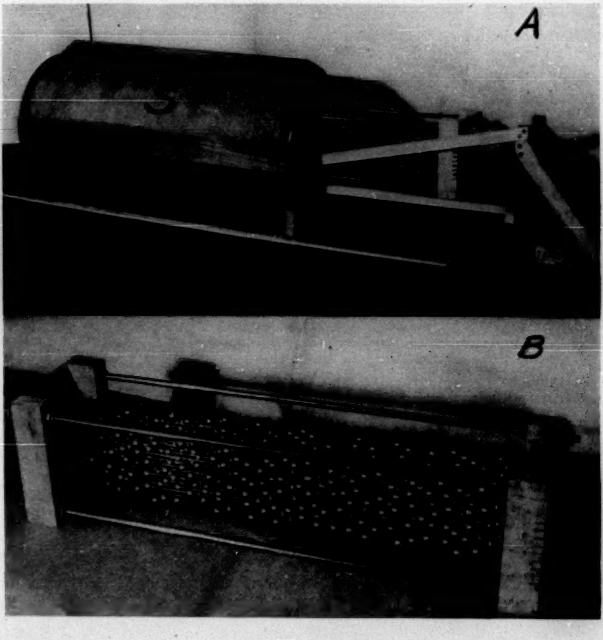
It will be recalled that if moist air is suddenly expanded it cools, and if an ionizing ray is passing through the chamber at the instant of the expansion, water droplets from the cooled moist air will deposit upon the ions and render the path of the ray visible. Mr. I. O. Myers is therefore putting a piece of magnetized iron into a cloud chamber of this type, Fig. 11, with the object of investigating the deviations of the cosmic rays, the energies of the rays concerned being measured by the deviation which they experience in a magnetic field prior to their entrance into the piece of magnetized iron.

FIG. 11.



As a preliminary to the foregoing experiment and because the mathematical calculations leading to $h + 2\pi I$ as the effective field for the case of randomly distributed rotating spheres is of rather a subtle nature, and further because the results predicted are quite surprising to many physicists, I have thought it worth while to perform an experiment upon a kind of model of a piece of magnetized iron, in which the magnetic entities are represented by iron spheres randomly distributed, as in Fig. 12*A*, the spheres being magnetized by subjecting them to the magnetizing field of the solenoid *S*. The lower portion of the picture Fig. 12*B* shows the sphere assembly freed from a portion of its supporting structure, so that it may be clearly seen.

FIG. 12.



We are interested in finding the average field perpendicular to a path for all paths perpendicular to the axis of the model and not passing through any of the spheres, and we are interested in comparing this with the quantity B which can most conveniently be obtained by measuring the total magnetic flux through a coil which encircles the model perpendicular to its axis. The procedure which Mr. Wayne Lees and I have adopted to test these matters will be clear from the following: To measure the average field perpendicular to any line through the assembly of spheres, we used, as a probe, a very elongated narrow loop, 8 cms. long and 1 mm. wide, wrapped on a piece of thin wood, the whole being pushed into a very thin glass tube to define its form. This probe could be connected to an alternating current galvanometer, and an alternating field could be applied to the solenoid, the proper phase relations being maintained so as to cause the deflection of the galvanometer to lead to a proper measure of the average flux through the probe during a half cycle. The observations could be standardized by repeating the measurement in the absence of the iron spheres, in which case the galvanometer deflection would be determined entirely by the magnetic field in the solenoid alone, and this would be determined by the alternating current in the solenoid. The flux through the coil encircling the magnetic model could be determined with and without the model for the purpose of determining the ratio of B to the magnetic field produced by the solenoid.[19] A picture of the circuit diagram of the apparatus is shown in Fig. 13.

Measurement of the deflections associated with the induction B and the magnetizing field h, which to all intents and purposes is equal in this experiment to the magnetic field produced by the solenoid, gave $B = 0.15h$. From this we are able to compute the intensity I of magnetization by the relation $4\pi I = 0.15h$. Hence $2\pi I$ is $0.075h$, and the theoretical value for $h + 2\pi I$ which, according to my theory, should be the average field perpendicular to the length of the narrow testing coil, is 1.075h. The experimentally determined value for this field is 1.07h. The part of it represented by 0.07h which is the part of interest to compare with 0.075h, which is representative of $2\pi I$, thus agrees with that quantity to better than 10 per cent. Thus the experiment suffices to decide quite definitely that the quantity in question is $2\pi I$ and not twice this value, as might have been expected on a naïve interpretation of the electromagnetic theory, or two-thirds of this value, which has also been suggested by certain investigators from other considerations.

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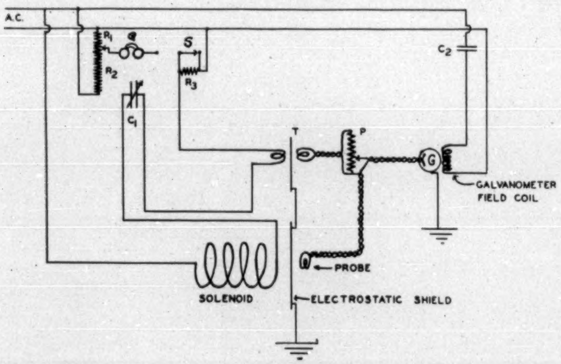
[19] The actual procedure adopted in the measurements was a little more involved than that described, and is outlined more fully in the caption attached to the circuit diagram, Fig. 13.

Fig. 13.



In practice, the electromotive force produced in the probe was balanced through a potentiometer arrangement P against an alternating e.m.f. from the transformer T excited primarily from the current which supplied the solenoid. The galvanometer was thus used as a null instrument.

The procedure indicated necessitates an adjustment to equality of the phases of the current in the solenoid and the current in the galvanometer field coil, because it is desired that the galvanometer shall respond to balance only for that portion of the probe e.m.f. which is in phase with the rate of change of current in the solenoid. The reason again for this requirement follows from the existence of eddy currents—in the iron spheres and solenoid core—which eddy currents produce spurious effects in the probe. The phase balance above referred to was secured by means of the bridge system whose arms are in order R_2, R_1, R_3, and the solenoid circuit. The condition for balance of the phases concerned is the possibility of securing absence of current in the telephone Q. S is a switch arm which can connect, as shown, for the purpose of operation, or to the telephone for the purpose of phase test.

I wish to take this opportunity of thanking the S. K. F. Industries, Inc. for donating the steel balls for this experiment, and Mr. R. F. Runge for his good offices in this matter.

INVESTIGATIONS CONCERNING COSMIC RAYS.

Last summer there was held at the University of Chicago a symposium on cosmic rays in which specialists from all parts of the world participated, and in which it is a happy thought to recall a most friendly atmosphere and a true brotherhood of science among individuals whose nations are now at each other's throats. There were Englishmen, there were Frenchmen, there were German Nazis, there were Jews. There were Italians, there were Dutchmen, Russians, and Americans of every geographical latitude. They were all sitting down harmoniously together, and I have a strong feeling that they would be just as harmonious if they sat down together again this summer. They had a difficult problem before them, that of finding out all that could be found concerning the nature of cosmic rays. The Bartol Foundation was well represented at this gathering, and its members presented, in fact, five papers which have since been published. I shall now cite some of the investigations concerned in these papers and subsequent developments in these and allied problems.

MESOTRONS AND COSMIC-RAY SHOWERS.

As stated in my last report, physics has learned during recent years of the existence of a new atomic particle, the mesotron, which has a mass about 200 times the mass of the electron, and which, in virtue of this mass, has properties characteristically distinct from those of the electrons. Thus, while electrons, in passing through a substance like lead, lose their energy rapidly by a process in which, from that very energy, new electrons are born, the mesotron loses its energy mainly by the process of ionization. Occasionally, however, mesotrons do lose energy by imparting large amounts of energy to electrons in atoms through which they pass. These electrons produce showers of other electrons by the process of multiplication, so that the mesotrons are accompanied by electrons which are ultimately of mesotron origin. We know this as a result of such experiments as those of Mr. Ramsey and myself performed in a mine 100 feet deep and described in my earlier reports, and elsewhere,[20] experiments in which we found the mesotrons to be accompanied in plentiful degree by electrons, in spite of the fact that it would be unreasonable to suppose that any electrons which existed above sea-level could be represented at these depths either in person or through their progeny.

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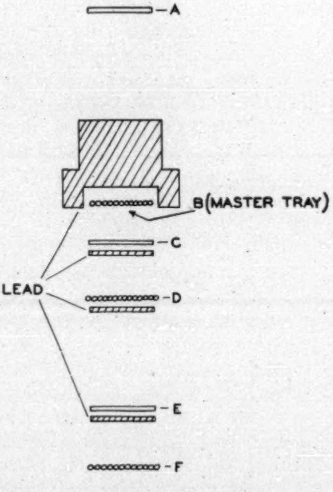
[20] W. F. G. Swann and W. E. Ramsey, *Phys. Rev.*, **54**, 229 (1938).

In my last report I described an apparatus designed by Mr. W. E. Ramsey and myself which was then just completed, for the purpose of investigating these showers produced by mesotrons. It will be convenient to give again a brief description of this apparatus before describing the results obtained with it. The apparatus is susceptible of various modifications, but in a typical form may be described diagrammatically by Fig. 14.

FIG. 14.



The apparatus,[21] as used in most of the experiments to be described in this report, comprises the following parts: First, there are three slabs of lead, shown cross-hatched, each 1 cm. thick. Above each slab, as shown in *C*, *D*, *E*, is an array of Geiger-Mueller counters. Each counter is 20 cms. long and 1 cm. in diameter. The counters are packed in trays, each tray forming a plane of counters with their axes parallel. Thus, a whole tray constitutes a square sensitive area, 400 sq. cm. in size. Above this assembly is placed a slab of lead 18 cms. thick, and on the top of this is placed an additional counter tray, *A*, similar to the others, and still another tray, *F*, is placed below all of the slabs of lead, as shown in Fig. 14. Counting from the top downwards, the successive counter trays are arranged with their counters alternately in perpendicular directions.

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[21] The apparatus is more completely described in: W. F. G. Swann, *Rev. Mod. Phys.*, 11, 242 (1939).

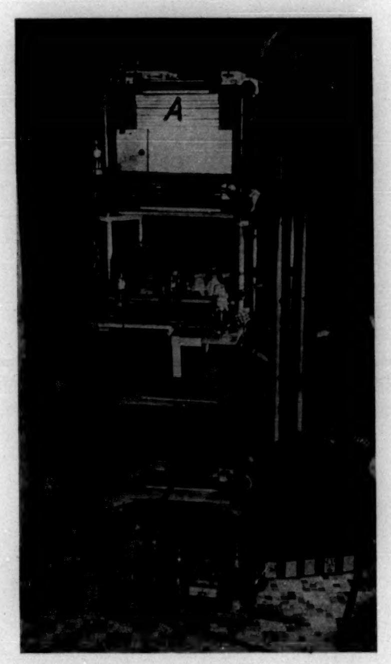
Every counter is connected to an individual electroscope, so that in all there are 180 such electroscopes. Each electroscope carries a mirror, and by means of a suitably designed optical system, each mirror is caused to shine a spot of light upon a ground glass screen so that, corresponding to each tray of counters, there is a row of spots.

In addition to the tray of counters so far described, there is another tray, *B*, which has no electroscopes associated with it. It is, however, surrounded on the sides by a 3 inch protection of lead so that no electrons of ordinary energy coming from outside can reach it.

Now the electrical circuits associated with the counters are so arranged that none of the electroscopes are permitted to operate unless at least one counter in the tray, *B*, one counter in the top tray, *A*, one in the bottom tray, *F*, and one in some of the intermediate trays discharge simultaneously. The control thus provided insures that any electroscope deflection recorded is associated directly or indirectly with a ray which has passed through all of the slabs of lead, and in particular the 18 cms. slab, and which may thus be regarded in general as a penetrating ray. There is no chance of a shower of electrons of normal energy coming from the side imitating the passage of a ray through the apparatus as the result of various trays being operated by different members of the shower because the lead shield around *B* prevents any electrons reaching that counter, whose operation in conjunction with its fellows is necessary if the apparatus is to permit deflection of any of the electroscopes.

When the simultaneous discharge of one or more counters in the trays aforesaid permits the electroscopes to operate, the deflections of the spots, from the electroscopes, which result, provide a complete record of all that has happened as regards

FIG. 15.



The apparatus is here shown set up with six counter trays associated with their electroscope systems, in addition to the extra tray hidden by the lead and which has no electroscopes. At the top of the column is the mass of lead, *A*, 18 cms. in thickness. Immediately above and below this mass of lead are two counter trays which are not very visible on account of foreshortening. To the right of each, however, will be seen the boxes, *B*, which contain the electroscope systems. Half way down the diagram is another counter tray which is quite visible, and below it in succession are three others, the directions of the counters in the successive trays being alternately perpendicular to one another.

V.2
19

shower production produced in the various slabs of lead and initiated by the passage of at least one penetrating ray through the whole apparatus. In this way, we have a means of tracing the initiation and growth of a shower phenomenon in the various pieces of lead, and we have a guarantee that such shower phenomena must have originated from mesotrons, since only such rays—with very rare exceptions—could pass through 18 cms. of lead. Figure 15, taken from my last year's report, is a picture of the apparatus, and the essential details will be clear from the caption.

FIG. 16.

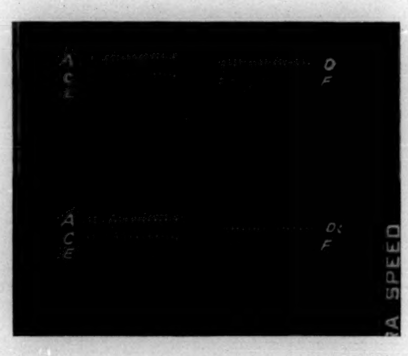


Figure 16 (No. 39) shows five rows of eighteen spots, corresponding to five counter trays. The order of the trays, from top to bottom, is *A*, *C*, *D*, *E*, *F*, in accordance with the scheme in Fig. 14. The displacement of one spot in each row indicates the passage of a single ray through the whole apparatus. In Fig. 16 (No. 31) we have, in addition to a single ray passing through the whole apparatus, an extra ray which has presumably originated in the 1 cm. slab of lead above tray *D*, which has shown itself by giving rise to an extra displaced spot in row *D*, and which is presumably an electron, since it is absorbed in the lead below and does not record in *E* or *F*.

It may be added that the whole apparatus is mounted in the lower 12 ft. section of a vertical iron tank, under 30 feet of water, which serves to add a further guarantee of the absence of any electrons originating above sea-level in these experiments, and which incidentally permits the performance of experiments for different thicknesses of water.

Correlation of the Experiments with the Theory of Shower Production.—H. J. Bhabha [22] has developed a theory of shower production by mesotrons, according to which he calculates the number of cases in which, in the equilibrium condition in lead, a mesotron is accompanied by one electron, two electrons, or, in general, n electrons. Some of his results are shown, under the heading "Theoretical," in Table I, where E is the energy of the mesotron and m the rest mass. The numbers in question are given for a 100-electron mass mesotron, except for the case $E - mc^2 = 10^8$, where they are given for a 10-electron mass mesotron. They do not vary very drastically with the energy of the mesotrons over the range 10^8 and 10^{12} for the quantity $E - mc^2$.

TABLE I.

Comparison of Theory of Shower Production with Experimental Results

Number of cases out of 1000 in which we would espect one mesotron of given energy specification to be accompanied by n rays.

Energy Specification.	n = 1.	2.	3.	4.	5.	6.
$E - mc^2 = 10^8$ e.v.	24	4	2.6	1.4	—	—
10^{10} e.v.	45.6	14	9.8	5.6	3.7	1.2
10^{12} e.v.	45.6	14.9	11.0	6.0	4.0	1.4
Below 20 cms. Pb	34	10	2	2	0	0
Below 30 cms. Pb	37	10	4	4	0	0
Averages for data	35	10	3	3	0	0
Averages corrected for counter inefficiency	44	15	6.0	7.0	0	0

In the same Table are given, under the heading "Experimental," the results for the numbers of single shower rays, twos, threes, and fours, etc., below 20 cms. of lead, and also the numbers below 30 cms. of lead. The total numbers for both cases are also given. It will be observed that both as regards the actual number of single additional rays accompanying the mesotron and as regards the relative number of cases in which two rays, three rays, four rays, etc., accompany the mesotron, our data are in satisfactory agreement with the theoretical values for the case of energies comparable with 10^{10} to 10^{12} e.v.[23] These results are digested from our most recent measurements taken subsequent to those published earlier.[24] However, they agree with these earlier observations as regards order of magnitude, but are more reliable on account of improvements in the apparatus.

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[22] H. J. Bhabha, *Proc. Roy. Soc.*, **164**, 257 (1938).

The foregoing observations show that Bhabha's theory is probably correct as regards the essentials of the acts involved in the production of these showers. However, there is another respect in which the predictions of the theory require confirmation or amendment. We should naturally expect that the richness of shower phenomena accompanying the passage of a mesotron through matter would depend upon the nature of the matter. Theory supports this expectation in principle; but various compensating elements suggest a net result to the effect that the shower production phenomena are largely independent of the material. It is convenient to specify the material in terms of the so-called atomic number which, as you will recall, is approximately proportional to the atomic weight.

In line with the foregoing ideas, Mr. Ramsey and I have, therefore, measured [25] the frequency of shower production for different numbers of rays for lead, tin, iron, and magnesium. Figure 17 shows the results. Horizontally are plotted the atomic numbers of the elements concerned. The ordinates represent the numbers of showers of the kind cited associated with the passage of 1000 mesotrons through the apparatus.

The two-electron, and perhaps the three-electron showers, show frequency of occurrence which is independent of the atomic number within the limits of accuracy of the experiments; but the one-electron showers show a marked dependence upon atomic number, a dependence sufficiently strong to dominate the situation even if we should plot a curve representing the *total* number of shower rays associated with 1000

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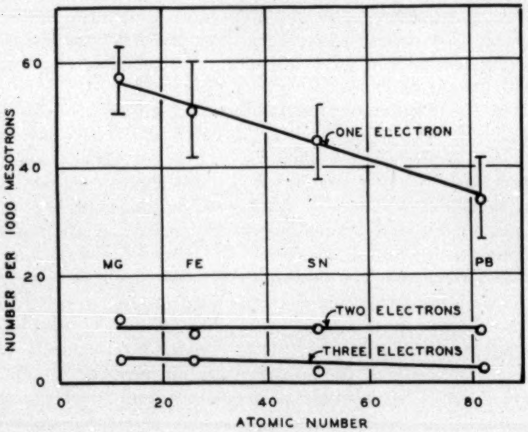
[23] The numbers are for electrons of energy greater than 10^7 e.v., the critical energy for lead. If energies below this are considered, the numbers should be doubled. Many of the electrons below 10^7 e.v. would, however, not record in our counters.

[24] W. F. G. Swann and W. E. Ramsey, *Phys. Rev.*, **56**, 378 (1939); W. F. G. Swann, *Rev. Mod. Phys.*, **11**, 242 (1939).

[25] W. F. G. Swann and W. E. Ramsey, *Phys. Rev.*, **57**, 749 (1940).

FIG. 17.



mesotrons. These results, therefore, are not in complete harmony with the elementary conclusions from Bhabha's theory which, as I have said, predicts results practically independent of atomic number.

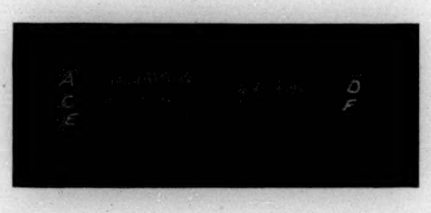
There is another point concerning these measurements to which I should like to refer. It is not often that the physicist is troubled by the fact of there being too great a harmony between his experiments, and yet we have a little trouble of this kind in respect of Fig. 17. Since we only measure a finite number of cases, of single shower rays for example, and to the extent that the arrival of such rays in our apparatus is governed by random phenomena, we should expect that the measurement of any finite number of events in an assigned time would be in error for the purpose of calculating the true average for that time in the same sense that in the case of slowly falling rain the counting of a few drops falling on a given area in a comparatively short time would be in error in respect of its prediction of the true average rainfall on that area for a much longer time. In Fig. 17 the vertical lines associated with the points on the curve represent the average uncertainty which we should expect as regards the predictions of our observations and resulting from this phenomenon. However, the points seem to lie on a smooth curve of such definiteness of form as to argue against this form being accidental and limited in certainty to the extent to which the statistical considerations would lead us to expect. The significance of this matter suggests speculations of a rather deep-seated nature which are, however, beyond the limits of possibility of discussion here.

Showers of Mesotrons.—While a very large amount of information exists concerning cosmic-ray showers, the rays in these showers are composed almost entirely of electrons, even though they may have originated from a mesotron through the intermediary of a single electron ray ejected by it according to the principles we have just discussed. However, it is of interest to enquire whether there may not exist showers of mesotrons themselves, although theory provides at present for no very clear-cut mechanism for the creation of such showers.

If in the shower-measuring apparatus I have described we should observe a case where two counters, and only two counters, in each of the several trays below the 18 cm. block of lead registered the passage of a ray, we should, barring certain exceptions as regards interpretation, have a guarantee that two rays had simultaneously passed through our apparatus and incidentally through each of the 1 cm. slabs of lead above the counter trays without shower production. This would be a guarantee that the two rays in question were mesotrons; for there is very small probability that a single electron ray could travel through a 1 cm. block of lead without shower production and a decreasingly smaller probability of its passing successively through additional 1 cm. slabs of lead without shower production.

In our Chicago Symposium paper of last summer,[21] we reported what I believe is the first evidence for the existence of mesotron showers observed by the foregoing procedure; and we reported other cases of a specially drastic kind in which numbers of counters comparable with the total number in each tray were discharged simultaneously as the result of one of these shower events. In Fig. 18 is an example of such a large shower. The arrangement of the apparatus is as indicated in Fig. 14. The picture shows that all the counters in the first tray *A*, 14 counters in the second tray *C*, 14 in the third tray *D*, 12 in the fourth tray *E*, and 13 in the fifth tray *F* give a record. It is natural to suppose that this picture represents a portion of a large shower coming from above; and it is natural to suppose that there are several mesotrons in the shower since, if there were only one, and if the remainder were electrons which were absorbed in the upper piece of lead, we should not expect a perpetuation of the abnormality represented by the discharge of so many counters in the trays below the upper piece of lead.[26]

FIG. 18.



Since last summer we have obtained further evidence on the production of these mesotron showers by the analysis of 2300 pictures [27] of cosmic-ray shower events obtained in our apparatus. The results are best represented in the form of a table. Table II refers in each case to a situation where one

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[26] One can never be immediately certain that rays which can penetrate great thicknesses of lead are not electrons of *exceptionally* high energy, particularly in view of recent evidence drawn from the existence of "extensive" showers. The crucial test would involve ascertaining unambiguously whether the shower rays multiplied in lead. This is not so easy in the case of a large number of rays. The fact that our experiments were performed below 30 feet of water diminishes the probability that the rays in question are electrons.

[27] This refers only to the experiments devoted to this particular phase. In all, we have about 7000 cosmic-ray shower records taken with different sorts of arrangements as regards disposition of material and counters.

TABLE II.

Nature.			Number.	Events.	2-ray Mesotron Showers per 10^4 Events.
Trays.	Recorded.	Blocks.			
4	4	3	2	2300	20
4	3	3	1	2300	7
5	3	4	1	550	20

ray entered the 18 cm. block of lead, and resulted in a pair of rays recording in the counter tray areas below the lead in the manner indicated in the Table, which will be understood from the following scheme of designation: Under the heading *Nature*, the column *Trays* indicates the number of analyzing counter trays below the 18 cm. block. The column *Recorded* indicates the number of trays in which two rays recorded. The column *Blocks* indicates the number of individual 1 cm. blocks of lead, below the 18 cm. block, through which the pair passed and recorded subsequently *without multiplication*. The column *Number* indicates the number of cases of the kind observed in the number of events shown in the *Events*. If the numbers in the column headed *Number* were large, each case would provide a basis to allow for counter inefficiency through utilization of the numbers under the *Trays* column, and so to calculate the number of two-ray showers to be expected in 10,000 events. Such calculations, when made from the few events recorded, are given in the last column. Naturally they show wide statistical fluctuations, but serve to give an order of magnitude of 16 mesotron pairs per 10,000 events.

In addition, in the data recorded last summer, 555 events gave one case of a single ray entering the 18 cm. block and emerging as 4 which passed through one 1 cm. block without multiplication. 570 events gave 3 cases in which 2 rays entered the thick lead block and continued as a pair through an additional 1 cm. of lead. 555 events gave 2 cases where two rays entering the thick block emerged therefrom and passed as 2 rays through 4 individual 1 cm. blocks of lead. In the recent observations, 2300 events gave 7 cases where two rays entering the thick block passed in addition through three individual lead blocks without multiplication or reduction.

Last summer we recorded several cases where an event was accompanied by an excitation of nearly all the counters above and all the counters below the thick block of lead. In our most recent experiments we observed nine cases out of 2300 events where the event concerned was associated with the excitation of more than 10 counters in the tray above the thick lead block and with a perpetuation of the excitation to the counters below the lead block with no more reduction than would be expected from counter inefficiency, and without evidence of multiplication, although in such cases multiplication is difficult to rule out. It may be added that all of these experiments were performed below a 30 ft. column of water.

The Absorption of Mesotrons in Different Materials.—It is important for theoretical investigations to know the coefficient of absorption of mesotrons in different materials. In other words, we desire to know the fraction of the mesotrons which, on entering a slab of the material, are absorbed in passing through 1 gram per square centimeter of the material. The acquisition of such data necessitates measurement of the mesotron intensity for different thicknesses of the material concerned. The most elementary theories of the absorption of mesotrons in matter suggest equal absorption for different substances in thicknesses which are equivalent in mass per unit area. More modern theories, however, predict results of a different nature.

Using the 30 ft. column of water in the tank already referred to, Dr. T. H. Johnson and Mr. M. A. Pomerantz[28] have compared the absorption of mesotrons in water and lead and have found that for equal mass equivalents the stopping power in water is greater than that in lead in the ratio 1.72 to unity, a conclusion well in harmony with the theoretical value 1.82 cited by H. A. Bethe and F. Bloch.

A comparison of the coefficients of absorption for heavier elements is being made by Mr. Ramsey and myself, using the counter tray apparatus employed in the shower experiments. The procedure adopted is to measure the mesotron intensity below a thickness of the material sufficiently great to insure that equilibrium has been established between mesotron intensity and electron intensity, and then make further measurements with an additional known thickness of the material concerned. As a preliminary to such a measurement, it is desirable to determine the data to construct a curve showing the relation between mesotron intensity and thickness of material, so as to find how thick a layer we must have in order that the change produced by a small additional thickness may correspond to the equilibrium condition aforesaid as exemplified by a linear decrease of intensity with thickness. Such a curve is shown in Fig. 19. We have considered that any

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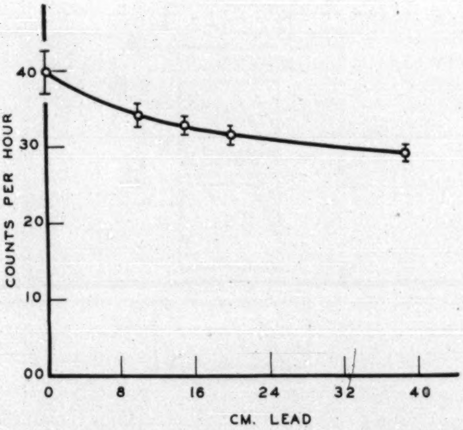
[28] M. A. Pomerantz, *Phys. Rev.*, 57, 3 (1940).

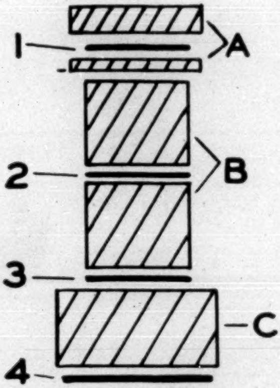
FIG. 19.



thickness equal to or greater than 15 cms. is, therefore, satisfactory for the minimum thickness. If we now wish to determine the absorption in an assigned thickness of lead, tin, or any other material, we put the specimen in question above 15 cms. of lead and immediately below the upper tray of counters. Sets of observations taken under the two conditions then supply the data necessary for calculating the coefficient of absorption. While the observations are yet in progress with a view to obtaining a sufficiently large number to insure a satisfactory accuracy, the following preliminary results for tin and lead are of interest. For lead, the mass absorption coefficient is 2.3×10^{-4} and for tin it is 2.4×10^{-4}. These are nearly equal, which is in harmony with theories of the subject, which give approximate equality of mass absorption coefficient for high atomic numbers, even though the numbers bear to each other a ratio of considerable magnitude.

The absorption of mesotrons by different substances is also being investigated by Mr. Pomerantz, using the modification of the foregoing procedure shown in Fig. 20. The counter trays 1, 2, and 3 comprise a triple coincidence counter train in which may be interposed a quantity of lead. This, therefore, serves as a mesotron analyzer in the sense that all particles which are able to discharge all three trays are mesotrons. Tray 4 is of such dimensions that all particles which penetrated the triple coincidence train must pass through it. The experiment consists of interposing the material to be investigated above tray 4. After taking into consideration the efficiency of the apparatus, the difference between the number of triple coincidences among trays 1, 2, and 3 and the number of quadruple coincidences among trays 1, 2, 3, and 4 represents the number of mesotrons which have actually stopped in the

FIG. 20.



absorber under consideration. In this way the thickness of absorber *a*, which stops the same number of mesotrons as a given thickness of absorber *b*, can be determined.

The same apparatus is also being utilized for the comparison of the absorption of fast mesotrons after traversal of different materials. This is accomplished by interposing the material to be studied between trays 1 and 2 and trays 2 and 3, and measuring the absorption coefficient of the mesotrons which penetrate this material by interposing lead between trays 3 and 4.

Cosmic-Ray Investigations with a Large Cloud Chamber.—In former reports, I have frequently had occasion to refer to investigations of cosmic-ray phenomena by the cloud chamber method, which has the potentiality of making the phenomena almost directly visible to the eye. As the complexity of the phenomena has increased, it has been necessary to draw more and more upon the refinements of cloud chamber technique, which are not readily realizable in small chambers, and to adopt measures which increase the numbers of pictures obtainable within a reasonable length of time.

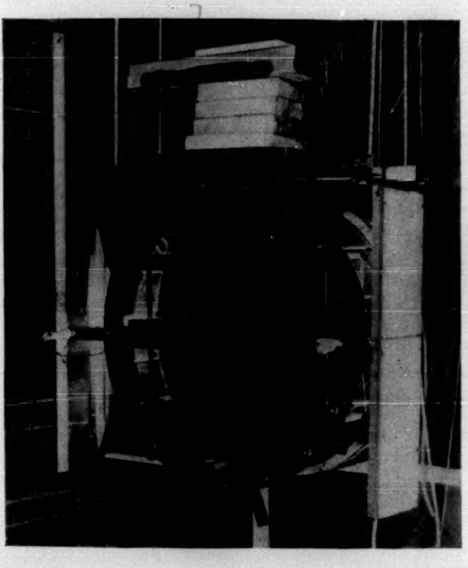
With the foregoing object in view, Dr. T. H. Johnson, in collaboration with Dr. J. G. Barry and Mr. R. P. Shutt, has designed and put into operation a cloud chamber of this type whose special features are the following:

1. It has an unusually large diameter of 58 cms., a depth of 15 cms., and contains within it 3 plates of lead totalling 7 cms. in thickness.
2. Coils are being constructed by means of which a magnetic field of more than 2000 gauss can be produced throughout the volume of the chamber for deflecting the cosmic rays and, thus, for measuring their energy.
3. Special features to provide for freedom from disturbing air currents during expansion have been incorporated, and a particularly efficient light source for the purpose of photography has been devised.

As a result of these improvements, it has been possible to realize a condition in which very satisfactory photographs have been obtained almost from the commencement of operation of the apparatus.

Figure 21 is a picture of the cloud chamber, and Fig. 22, which represents a single cosmic ray passing through three lead plates inserted in the chamber, serves to indicate the degree of refinement of detail attainable. The middle plate has a thickness of 5 cms., while the other two are 1 cm. thick.

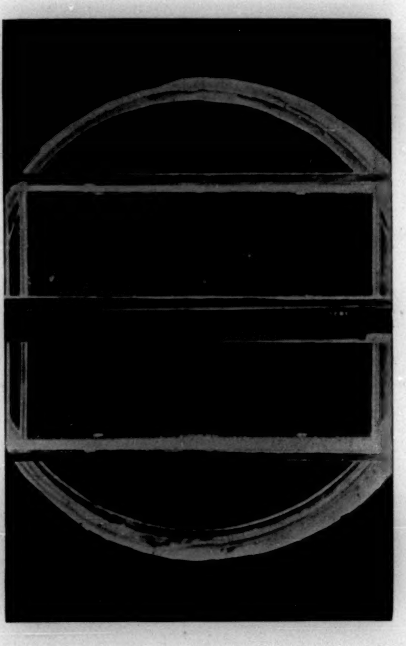
FIG. 21.



With the foregoing cloud chamber, the intention is to investigate as many as possible of the characteristic features of the life history of mesotrons, for example, their shower-producing characteristics, the act of emission of an electron at the death of the mesotron, etc., and the deflections which mesotrons suffer in the act of ejecting electrons from atoms in a gas.

While a systematic investigation of these phenomena awaits a completion of the magnetic field producing coils which will be associated with the apparatus for the measurements of the energies of the rays, certain interesting photographs have already been obtained. Figure 23[29] shows a mesotron *A* which penetrates all of the lead plates without multiplication. Other rays *B* and *C* either stop in the 5 cm. lead plate or pass out of the chamber. At *S* we have a large electron shower showing such multiplication. The parallelism of rays *A*, *B*, *C*, and the group *D*, seems to suggest a com-

FIG. 22.



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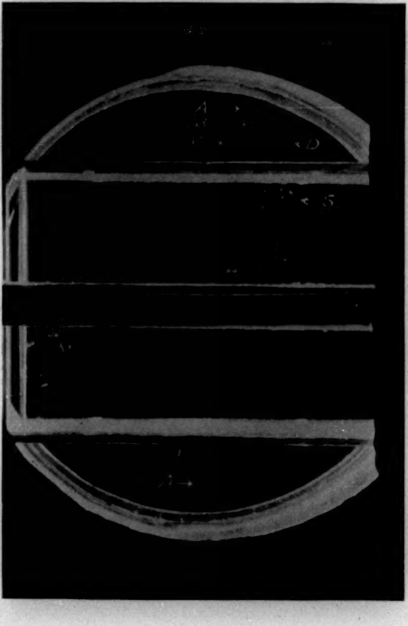
[29] Stereoscopic photographs have been taken in all but the first batch of exposures, but for convenience of general description, only single members of the stereoscopic pair are here shown. Slides of some of the stereoscopic photographs were shown at the lecture.

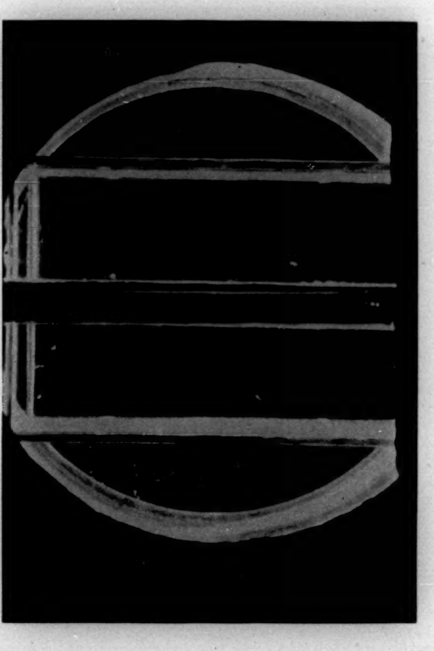
mon origin and to imply that the whole shower phenomenon represented by the picture has its parentage in this origin. Figure 24 shows a case where a mesotron particle has ejected a secondary of high energy from the actual gas of the cloud chamber itself. Figure 25 shows a mesotron which has passed through 5 cms. of lead, but has suffered a strong deflection therein. Such a deflection is indicative of an interesting atomic process in which the mesotron has participated in the lead. Figure 26 shows one of these cases in which the mesotron passes through the first piece of lead without multiplication, but in the second piece of lead three rays, in addition

FIG. 23.



to the mesotron itself, are ejected and two of these accompany the mesotron through the third piece of lead 1 cm. thick, without producing other secondaries as electrons would be expected to do. Hence, it is concluded that these particles are probably mesotrons.

FIG. 24.



Further Investigations on Shower Phenomena.—As part of the Chicago cosmic-ray symposium already referred to, Dr. and Mrs. C. G. Montgomery [30] have presented a paper summarizing in consistent order their various investigations on large cosmic-ray showers described in several publications in the literature and in my former reports. In addition, they have brought forth certain new aspects which I shall attempt briefly to summarize. It will be recalled that the ordinary theory of the origin of small electronic showers invokes what is customarily called the cascade process, in which an electron entering a piece of matter loses its energy rapidly in its journey through by the emission of photons, which are jerked into existence in its encounter with the various atoms by which it passes. These photons, again through the influence of the atoms by which they pass, and in accordance with the principles of atomic physics, possess the power to materialize into

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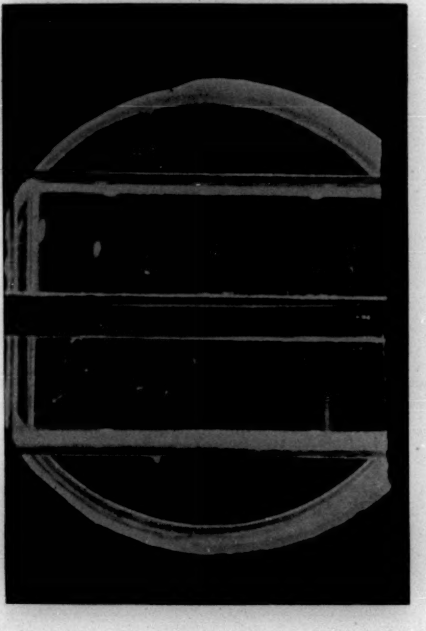
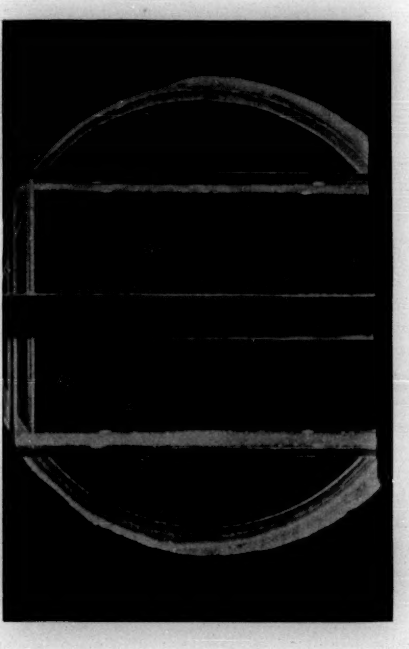
[30] C. G. and D. D. Montgomery, *Rev. Mod. Phys.*, 11, 255 (1939).

FIG. 25.



positive and negative electrons, which then repeat the process which consequently goes on through successive generations of progeny, leading ultimately to a shower which may contain numerous particles. The larger the energy of the original electron, the larger the size of the shower produced.

FIG. 26.



Now in cosmic-ray observations, we occasionally observe showers containing many thousands of particles, and there has been some question as to the origin of these larger showers. If they are to be supposed as produced from electrons by the cascade process, it is necessary to account for the existence in the atmosphere of a sufficiently large number of high energy electrons to account for the frequency of occurrence of large showers. The electrons to be found at any given altitude may be divided into three categories. First, primary cosmic-ray electrons may be transmitted in cascades directly from the top of the atmosphere. Second, on their passage through the air, some of the cosmic-ray mesotrons disintegrate into electrons and neutrinos, and the electrons are propagated to lower altitudes. Third, occasionally a high energy mesotron will collide with one of the atomic electrons in the material through which it is passing and knock on the electron, giving it a high energy.

Now depending upon the experimental conditions, and in particular upon the altitude, or depth below sea-level, these three sources of electrons will be relatively more or less important for the production of large showers. It is possible to calculate from existing theories and the observations of the cosmic-ray intensity the relative importance of these different sources of electrons, and the numbers of electrons of any assigned high energy which are to be expected. It turns out that the number is sufficient to provide for the production of the large showers.[31] This conclusion has been fairly widely recognized as of considerable importance, because it was formerly maintained by high authorities, but on the basis of a less exhaustive quantitative analysis of the situation, that some process other than the cascade process initiating in an electron was necessary to account for these large showers.

As part of the foregoing investigation, Dr. and Mrs. Montgomery have also shown that the number of electrons and photons in the high energy range responsible for large showers is also sufficient to give rise through atomic nuclear disintegration to such slow protons and neutrons as are found in the cosmic radiation. This hypothesis is substantiated chiefly by such observations as those of Dr. S. A. Korff of our laboratory, observations which show that the variation with elevation of the number of protons and neutrons is identical with that of the large showers observed under thin layers of lead in the range from sea-level to the altitude of Pike's Peak.

Another allied matter of interest is the following: If there comes into the top of the atmosphere an electron of sufficiently high energy to result in it or its progeny penetrating to sea-level, we shall have in the resulting shower at sea-level a distribution of energies of all magnitudes in the range concerned. However, it is a characteristic feature of these atomic processes that the high energy progeny of a high energy parent perpetuate in very exact degree the direction of propagation of the parent. Hence, the axis of a shower of the kind cited and the cylindrical region closely surrounding this axis may be expected to be the region in which high energy electrons will be found. The whole shower beam, in fact, will tend to concentrate itself in such a cylindrical region, for if in the journey from the top of the atmosphere any electrons are shot out at an appreciable angle to the central axis, that fact itself is a criterion of their low energy, and of their consequent inability to travel much further.

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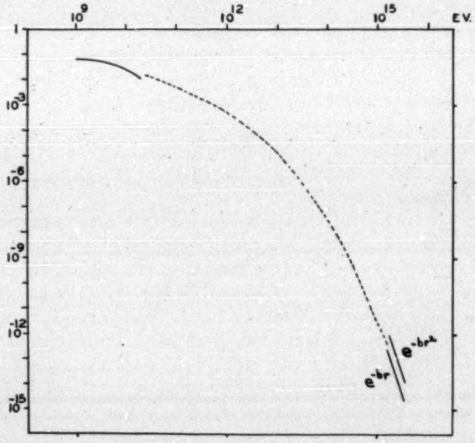
[31] C. G. and D. D. Montgomery, *Rev. Mod. Phys.*, 11, 255 (1939).

Now, it turns out that the density of electron distribution in one of these cylindrical beams is related in an unambiguous way to the energy of the primary electron which, by entering into the atmosphere, is responsible for it. By assumption that the large showers observed at sea-level arise according to the foregoing mechanism, Dr. and Mrs. Montgomery have been able to calculate the numbers of electrons which, on entering into the atmosphere, lie between any assigned ranges of energy in this high energy region. The results are best given by Fig. 27, which is more fully explained in its caption. The ordinates represent the logarithms of the actual numbers of electrons per unit solid angle, per unit of time, per unit of area, lying above the energy whose logarithm is plotted in the horizontal direction. This number is presumably the same for all directions outside of the atmosphere. It is of interest to see how these results represented by the short full lines at the bottom of the graph tie up with those for lower energy ranges shown by the full line at the top of the graph and obtained by direct measurement. Such additional data are also represented in the figure by the dotted graph. It will be seen that the problem of harmony between the two sections of the curve presents no problem of apparent difficulty.

It may be added that while the distribution of ordinary cosmic-ray intensity with latitude and direction provides us with information as to the energy distribution for incoming cosmic rays in the energy range below the highest energy which can be excluded by the earth's magnetic field, such deductions as those carried out by Dr. and Mrs. Montgomery, and depending on measurements of the large showers, provide

Fig. 27.



The description in the text may be supplemented as follows: The two short full lines at the bottom of the graph correspond to two different assumptions as to the variation of density of shower rays with the distance r from the center of the shower. According to one of these assumptions, the density varies proportionally to ϵ^{-br}, and according to the other it varies proportionally to ϵ^{-br^2}. The full line at the top of the graph, representative of the lower energy ranges, is connected with the aforesaid region by a dotted line which serves to indicate the extent to which the energy distribution for one energy range can be extrapolated into that for the other.

the only means we have of elucidating information concerning the distribution of energy in ranges far above those which respond in measurable degree to the earth's magnetic field.

NEUTRONS IN COSMIC RAYS.

High Altitude Determinations.—Last year I described experiments by Dr. S. A. Korff and Dr. W. E. Danforth leading to the development of very satisfactory and convenient forms of Geiger counters capable of detecting neutrons [32] which, as you will recall, are neutral uncharged high energy particles. The extent to which neutrons are associated with cosmic rays presents a problem which for some time has been of significant interest for students of the subject. Indeed, last year I reported measurements of Dr. and Mrs. Montgomery on the neutron intensity at sea-level, which show that the intensity as measured by numbers of rays is of the order of 1/20th of the cosmic-ray intensity.

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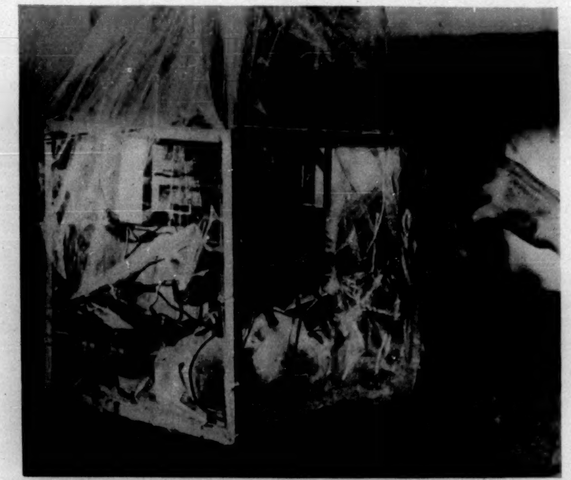
[32] S. A. Korff and W. E. Danforth, *Phys. Rev.*, **55**, 980 (1939).

FIG. 28.

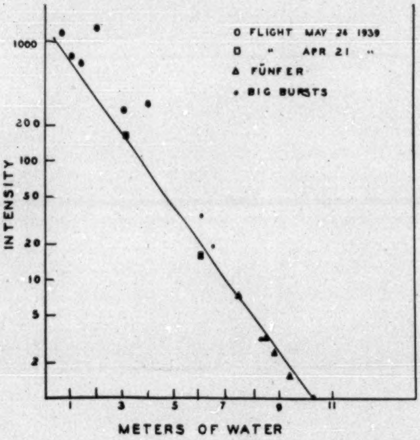


Radio-cosmic-ray equipment ready for balloon flight. Cellophane cover keeps sun's heat inside by greenhouse effect while stratosphere temperatures outside may fall to − 60°. Batteries, vacuum-tube control circuits and the cosmic-ray counter may be seen inside. This instrument measured several different counting rates, and is probably the first experiment with its own control-conditions to be made in the stratosphere.

Now it is of profound importance to determine how the neutron intensity varies with altitude, for this provides information concerning the processes which are involved in the production of these neutrons, as has already been pointed out in connection with the work of Dr. and Mrs. Montgomery on large showers. In view of these considerations and, of course, on general principles, Dr. S. A. Korff has extended these measurements to high altitudes by utilizing the general principles of the radio-balloon technique which he and Dr. T. H. Johnson have developed in connection with a variety of cosmic-ray high altitude investigations.

A picture of the apparatus is shown in Fig. 28 and is described in sufficient detail in its caption. It will suffice here to say that a neutron counter measured the neutron intensity as contributed from all directions, the reception of each neutron being transmitted by a radio device to a ground station from the high altitude reached by the apparatus. These results are best represented in the form of a graph, Fig. 29,[33] in which they are compared with the observations of E. Fünfer, which observations, however, extended only to the altitude of about 2 miles, whereas Dr. Korff's observations extended to an altitude of about 14 miles. It is interesting to observe that between sea-level and an altitude representa-

FIG. 29.



V.
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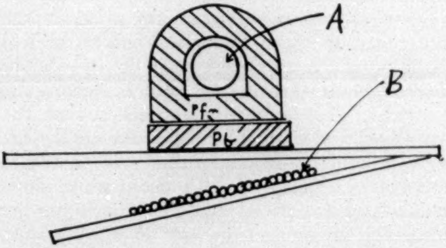
[33] S. A. Korff, *Rev. Mod. Phys.*, 11, 211 (1939).

tive of nine tenths of the atmosphere (about 14 miles) the neutron intensity increases by a factor of about 650, whereas the total cosmic-ray intensity itself increases by a factor of about 200.

On the same graph, Fig. 29, are plotted the observations by the Montgomerys of the large showers (called "big bursts" in the graph) at different altitudes. It will be observed that these large showers follow, as far as the observations go, the same law of increase with altitude as that for the neutrons, a fact already referred to in connection with what has already been written concerning the work of the Montgomerys on these large showers.

Direct Experiments on Associations between Neutrons and Cosmic-Ray Showers.—The close association between the variation of neutrons and large showers with altitude suggested to Dr. Korff an experiment performed at sea-level,[34] in which the two phenomena were compared directly. The experiment was as follows: *A*, Fig. 30, is a neutron counter with a tray *B* containing several Geiger counters below it, the electrical arrangements being such that a record was obtained only when the neutron counter discharged and simultaneous with that discharge there occurred a discharge of two or more of the Geiger counters in the tray. By such an apparatus one can find the number of neutrons which passed through the counter and which were associated with cosmic-ray showers. By destroying the coincidence feature, one may now determine

FIG. 30.



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[34] S. A. Korff, *Phys. Rev.*, **57**, 555 (1940).

the number of neutrons passing through the counter and the number of showers recorded by the apparatus in the same time as before, regardless of whether or not there was a coincidence between the two phenomena. These results do not lead immediately to quantitative information on the numbers of showers which are associated with neutrons, since the geometrical elements involved have different importance as regards the neutrons in the showers. However, it is possible to allow for these considerations to an extent sufficiently exact within the limits of accuracy of the measurements and by so doing Dr. Korff has concluded that about one in every 100 showers is accompanied by a neutron, and the frequency of correspondence between neutrons and showers increases with the size of the shower. This shows us that at any rate showers are occasionally associated with neutrons. It is possible, however, to ask from the data: How many showers accompany an assigned number of neutron observations? And through calculation, the further question: How many showers may be supposed to *accompany* the emission of *n* neutrons from a block of lead?[35] It turns out that the emission of 100 neutrons is accompanied on the average by the occurrence of approximately 80 showers, which latter number is sufficiently near to 100 to invite the belief that every neutron originating in the lead is accompanied by a shower. Incidentally, it may be remarked that the number of neutrons associated with showers in our apparatus is of the same order of magnitude as the number of protons which we would conclude as associated with these same showers from Carl Anderson's observations made in cloud chambers.[36]

The foregoing considerations are in corroborative agreement with a view proposed by Dr. Korff as to the mechanism of the processes involved, in which the fundamental starting point is a shower, one of whose photons has enough energy to disrupt the nucleus of an atom, producing by this disintegration neutrons and protons in relative amounts determined by the numbers in the nucleus, but in amounts which are always of the same order of magnitude.

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[35] The disentanglement of the neutrons produced in the lead from those produced elsewhere can be achieved by performing experiments with and without the lead.

[36] C. D. Anderson and S. H. Neddermeyer, *Phys. Rev.*, 50, 263 (1936).

Interpretation of the Significance of Neutron Measurements in Connection with Neutrons Associated with Cosmic-Rays.—The experiments of Dr. Korff already referred to have incited the interest of many theoretical physicists, and it seemed appropriate that a study and discussion of these matters should be undertaken in collaboration with Professor H. A. Bethe and Dr. G. Placzek, who have been specially interested in this field. The discussion which resulted,[37] involving as it does considerations of a rather deep-seated mathematical nature, is not readily amenable to condensation to semi-popular form. However, the results are perfectly clearcut and may be summarized as follows: We start with the concept of a neutron which has been produced in one of the atomic disintegration processes aforesaid, and which commences its life history with perhaps thirty million electron volts energy. The first thing of importance that happens to this neutron is that it crashes into the nucleus of a nitrogen atom of the air.[38] It produces a disintegration with the emission of one or more nuclear particles (alpha particles, neutrons or protons). The neutron may perform more than one of such acts, losing energy in each successive act. These amounts of energy are characteristic of the atom, which absorbs its tax in relatively large amounts at each encounter, so long as the neutron has any energy left which is worth consideration from the atomic standpoint. Once the neutron, however, has been robbed of all its energy, except for a residuum of 4 million volts, the atoms ignore any further tax and leave the neutron with its diminished wealth to expend in less ambitious processes.

Having gotten down to this lower bracket of energy, the neutron proceeds to bounce against the various atoms which it encounters, losing a certain amount of energy at each collision, but energy which no longer affects the nucleus of the atom which it hits, except in the sense of giving the whole atom some kinetic energy. After several hundreds of such collisions, the neutron's energy dwindles down to something comparable with the energy of temperature agitation of the surrounding gas molecules. As it is approaching this order of magnitude, when in fact it has attained an energy comparable with one volt, it again becomes interested in the nuclei of the atoms it, but in an apparently more humble, although in actuality, in a revengeful attitude. Instead of descending upon the nucleus as a decimating warrior, it comes as a humble suppliant for house room and after accommodation in this fashion by the charitable nucleus, it shows itself in its true colors as a political agitator, boring from within and demanding duties and prerogatives which cannot be supplied by its host. As a result, a revolution is promoted and the nitrogen nucleus now of mass 15 in terms of hydrogen as unity blows up with the ejection of one of the innocent bystanders, the proton, leaving the neutron as part of a new and unstable government in the form of an unstable carbon nucleus of mass 14. Although the new government is unstable in the theoretical sense, it is quite stable compared with the governments of today, for its average period of existence is something like two or three hundred years. However, a sufficiently large number of these governments, in the shape of individual nitrogen atoms, can show their instability as a whole by the fact that they occasionally break down, emitting electrons and, strange to say, returning to the initial democracy, N_{14}, a suggestion from nature which will doubtless excite the hopes of many in these days.

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[37] H. A. Bethe, S. A. Korff, and G. Placzek, *Phys. Rev.*, 57, 573 (1940).

[38] For definiteness in our language of description, we speak of the nitrogen atom only, although the oxygen atoms may also be involved. From a nuclear standpoint, however, the oxygen atoms are so similar to the nitrogen atoms, in all that is relevant for the purposes of discussion, that we may make the argument entirely for nitrogen.

From the purely practical side it may be said that these theoretical considerations have enabled us to understand more thoroughly the significance of Geiger counter measurements and of other methods for observing neutrons in relation to their interpretation in terms of the neutron intensity in the atmosphere, and they have thus served to harmonize certain observations of different investigators which formerly had appeared inconsistent on account of errors of interpretation of the results, following from the use of incomplete theories in breaching the gap between the experiments themselves and their implied consequences.

The net result of the foregoing interpretations, when taken in conjunction with the experiments at high altitudes, shows that the neutron intensity, as measured by the numbers of rays, is comparable with the cosmic-ray intensity, a conclusion which Dr. Korff had reached (in the work already reported) last July by simpler but less detailed interpretations of his measurements.[33]

LATITUDE VARIATION OF THE COSMIC-RAY INTENSITY IN HIGH SOUTHERN LATITUDES.

When the Government undertook to send an expedition to Little America about a year ago, it was planned to include cosmic-ray measurements in the scientific program of the expedition, and Dr. Korff, who has had previous experience in cosmic-ray measurements in southern latitudes, was asked to formulate a cosmic-ray program, which he did and which is now in operation. As part of that program it was deemed advisable to extend observations of cosmic-ray intensity to various latitudes south of those in which measurements already had been made down to latitudes approaching those of the South Magnetic Pole.

Last summer, Mr. Eric T. Clarke came to the laboratory to gain general experience in our experimental work, and I assigned him to Dr. Korff's supervision for training in cosmic-ray measurements. This fitted in very well with the subsequent plan of sending him as an observer on the Antarctic Expedition. He took with him two Millikan cosmic-ray meters, belonging to the Carnegie Institution of Washington. One of these was used for the measurement of cosmic-ray intensity on board ship with the object of determining the latitude variations [39] and both of them were subsequently installed and are at present in operation in the permanent base at Little America. We have received from Mr. Clarke the results of his observations on the latitude variation obtained by the measurements on board ship, and Dr. Korff has made a reduction with the results shown in Fig. 31, which represent the cosmic-ray intensity as measured by the Millikan meter, plotted against the magnetic latitude.. These observations extend from magnetic latitude 53° N. through the magnetic equator to magnetic latitude 77° S. For comparison, the observations obtained in previous voyages by Millikan and Korff are shown, but they only reach to latitude 40° S.

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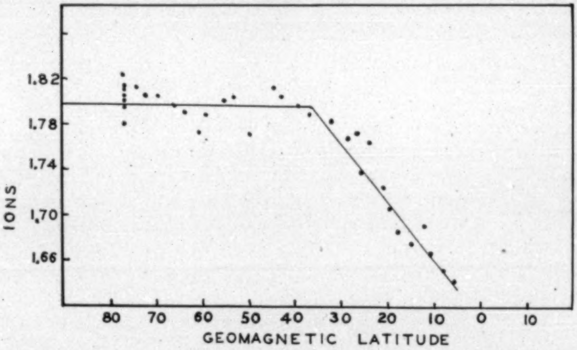
[39] It will be recalled that the Millikan meter measures the radiation from all directions, by the ionization produced in a closed vessel.

It is known that cosmic-ray intensities vary with the external air temperature. In Fig. 31, these variations are eliminated by application of the known value of the temperature coefficient, and they reveal the interesting fact that further variation of cosmic-ray intensity with latitude ceases, within the limit of accuracy of the experiments, at about 40° south magnetic latitude, where the former experiments of Millikan and Korff had terminated.

FIG. 31.



FURTHER COSMIC-RAY MEASUREMENTS AT HIGH ALTITUDES.

In my report last year, I referred to low magnetic latitude measurements by Dr. T. H. Johnson and Dr. J. G. Barry of the cosmic-ray intensity at high altitudes (comparable with 15 miles) with special reference to a comparison of the intensities from the east and from the west. The conclusion, as adjusted to Dr. Johnson's most recent calculations,[40] shows that the intensity measured at 60° from the zenith differed for the easterly and the westerly direction by only 7 per cent. This result, which led Dr. Johnson to certain interesting theoretical considerations referred to in my last report and in subsequent publications,[40, 41] is, nevertheless, surprising in terms of what had been the conventional views as to the conditions prevailing in the upper atmosphere. For this reason, Dr. Johnson felt it desirable to carry out certain confirmatory experiments with a view to ruling out considerations which might conceivably vitiate the simple interpretations of the results. The most prominent of the effects in line for consideration are those arising from the production of electron showers in the air by the primary entering electrons, which showers can discharge the three elements of a triple coincidence counter telescope by entering from the side and without having the direction defined by the telescope.

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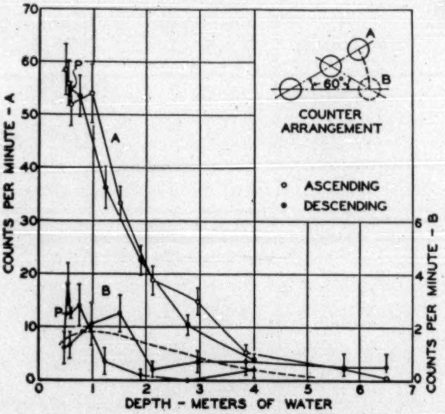
[40] T. H. Johnson, and J. G. Barry, *Phys. Rev.*, 56, 219 (1939).

[41] T. H. Johnson, *Rev. Mod. Phys.*, 11, 208 (1939).

FIG. 32.



The variation of in-line, *A*, and out-of-line, *B*, coincidences with atmospheric depth. The points *PP* are based upon 45-minute averages, the other points upon 5-minute averages.

In order to investigate the importance of these showers, Drs. Johnson and Barry[42] adopted the plan indicated at the top right hand corner of Fig. 32. There are three counters, arranged to record only when a ray passes through each simultaneously. However, these counters can be arranged in line, or out of line, transition from one case to the other being made at about two-minute intervals in the stratosphere by means of a small motor. The results of the observations were transmitted by radio to the laboratory station according to the technique already described in previous reports and other publications. The net result, the details of which are shown in the graph of Fig. 32 and described in the caption thereto, is to the effect that less than 5 per cent. of the rays recorded by three counters in line are due to showers.

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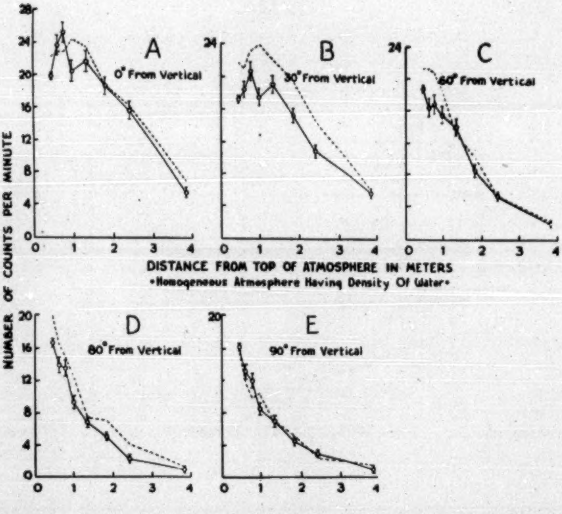
[42] T. H. Johnson and J. G. Barry, *Phys. Rev.*, 57, 245 (1940).

The foregoing results on the absence of the effect of showers in vitiating the simple interpretation of cosmic-ray data in the stratosphere are in harmony with the conclusions from certain precautions which we took with regard to these showers in connection with the 1935 National Geographic U. S. Army Corps stratosphere flight.[43] Here there were two sets of

FIG. 33.



V.2
19

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[43] W. F. G. Swann, G. L. Locher, and W. E. Danforth, *Nat. Geog. Soc. Contr. Tech. Papers*, Stratosphere Series, No. 2, 13 (1936).

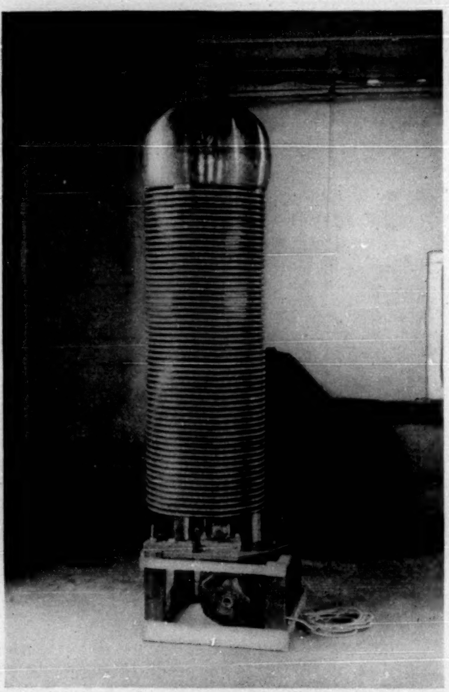
counter telescopes, one of the ordinary type and one provided with walls of shielding counters so arranged that any rays passing through the elements of a telescope other than along the line of a telescope would have to pass through the shielding wall. The electrical circuits were so arranged that if one or more of the shielding wall counters were caused to operate, the apparatus was prevented from recording a count by the corresponding counter telescope. Thus the unshielded counter telescopes recorded the observations contaminated by shower phenomena, while the shielded counter recorded the results free from contanimation. The former results are shown by the dotted line in Fig. 33, while the latter results are shown by the full lines. It will be seen that the effect of showers seems to be quite small, as indicated by the later experiments of Drs. Johnson and Barry.

DEVELOPMENT OF THE VAN DE GRAAFF GENERATOR.

We are installing a Van de Graaff generator designed to work under pressure of the order of 200 lbs. per square inch, and to produce voltages of the order of 2.4 million volts. This machine is primarily for work in nuclear physics. It is being fathered into existence under the immediate direction of Dr. W. E. Danforth, and we are greatly indebted to the Massachusetts Insititue of Technology, and particularly to Dr. R. J. Van de Graaff and Dr. J. G. Trump for providing us so generously with information regarding their designs. The machine is well on its way to completion and is represented in part assembly in Fig. 34.

And so, once more, I come to the end of my annual cafeteria-like address, with its assortment of commodities of all forms in the shape of investigations which, while diversified in nature, have I hope a consistent interrelation. To those for whom it has been too dry and involved I apologize, and suggest that their reward lies in the hereafter as a recompense for their faithful attendance at another periodic ritual. To those for whom it has been too elementary, I apologize, and suggest that in poetic justice for their sophistication they read the completed papers to which reference will be given in the printed report. For those for whom it has been too long, I can only express the hope that they slept well; but for those.

FIG. 34.



The picture represents at the top a conductor which attains the high potential. Below it are potential distributing rings, while the belts are invisible and are inside. The whole unit here assembled will be enclosed in a tank, not shown, at 200 lbs. per square inch pressure.

if any, for whom it has been too short, I have a warm place in my heart. I trust that this does not leave me completely devoid of friends.

APPENDIX

PUBLICATIONS OF THE BARTOL RESEARCH FOUNDATION FROM APRIL 19, 1939 TO APRIL 17, 1940.

1. Neutron Measurements with Boron-Triflouride Counters—S. A. KORFF AND W. E. DANFORTH. *Phys. Rev.*, 55, No. 10, p. 980, May 15, 1939.

2. The Adaptation of a Small Cloud Chamber to the Study of Electron Showers —J. EARL THOMAS, JR., AND W. E. RAMSEY. JOUR. FRANK. INST., 227, No. 6, pp. 789–799, June, 1939.
3. Recent Advances in Cosmic-Ray Investigation—T. H. JOHNSON. *Jour. Wash. Acad. Sci.*, **29**, No. 6, pp. 233–256, June 15, 1939.
4. Geiger Counter Measurements of the Vertical Cosmic-Ray Intensity between Sea-Level and 24,000 feet—W. F. G. SWANN AND W. E. DANFORTH. JOUR. FRANK. INST., 228, No. 1, pp. 43–61, July, 1939.
5. The Intensity of Neutrons of Thermal Energy in the Atmosphere at Sea-Level—C. G. MONTGOMERY AND D. D. MONTGOMERY. *Phys. Rev.*, **56**, No. 1, pp. 10–12, July 1, 1939.
6. Concerning Thermionic Regulation of Direct-Current Generators—W. E. DANFORTH. *Rev. Scient. Instr.*, **10**, pp. 211–217, July, 1939.
7. The East-West Symmetry of the Cosmic Radiation at Very High Elevations near the Equator and Evidence that Protons Constitute the Primary Particles of the Hard Component—T. H. JOHNSON AND J. G. BARRY. *Phys. Rev.*, **56**, No. 3, pp. 219–226, August 1, 1939.
8. The Angular Dispersion of the Cosmic Radiation in the Upper Atmosphere Resulting from Deflections of Low Energy Particles in the Earth's Magnetic Field—T. H. JOHNSON. *Phys. Rev.*, **56**, No. 3, pp. 226–231, August 1, 1939.
9. Correlation of Counter and Electroscope Measurements of Cosmic Radiation in the Stratosphere—S. A. KORFF AND W. E. DANFORTH. JOUR. FRANK. INST., **228**, No. 2, pp. 159–167, August, 1939.
10. Showers Produced by Penetrating Rays—W. F. G. SWANN AND W. E. RAMSEY. *Phys. Rev.*, **56**, No. 4, p. 378, August 15, 1939.
11. Science and Human Affairs—W. F. G. SWANN. JOUR. FRANK. INST., **228**, No. 3, pp. 263–291, September, 1939.
12. Slow Mesons in the Cosmic Radiation—C. G. MONTGOMERY, W. E. RAMSEY, D. B. COWIE, AND D. D. MONTGOMERY. *Phys. Rev.*, **56**, No. 7, pp. 635–639, October 1, 1939.
13. The Transition Effect for Large Bursts of Cosmic-Ray Ionization and the Number of Primary Electrons of Very High Energy—C. G. MONTGOMERY AND D. D. MONTGOMERY. *Phys. Rev.*, **56**, No. 7, pp. 640–643, October 1, 1939.
14. The Upward Radiation Produced by Cosmic Rays At High Altitudes—S. A. KORFF AND E. T. CLARKE. *Phys. Rev.*, **56**, No. 7, p. 704, October 1, 1939.
15. Evidence that Protons are the Primary Particles of the Hard Component—T. H. JOHNSON. *Rev. Mod. Phys.*, **11**, Nos. 3–4, pp. 208–210, July–October, 1939.
16. Recent Studies at High Elevations—S. A. KORFF. *Rev. Mod. Phys.*, **11**, Nos. 3–4, pp. 211–219, July–October, 1939.
17. Showers Produced by Penetrating Rays and Allied Phenomena—W. F. G. SWANN. *Rev. Mod. Phys.*, **11**, Nos. 3–4, pp. 242–254, July–October, 1939.
18. The Behavior of High Energy Electrons in the Cosmic Radiation—C. G. MONTGOMERY AND D. D. MONTGOMERY. *Rev. Mod. Phys.*, **11**, Nos. 3–4, pp. 255–264, July–October, 1939.

19. Discussion of "The Behavior of High Energy Electrons in the Cosmic Radiation"—C. G. Montgomery and D. D. Montgomery. *Rev. Mod. Phys.*, **11**, Nos. 3–4, p. 266, July–October, 1939.
20. A Portable Apparatus for Recording Bursts of Cosmic-Ray Ionization—C. G. Montgomery and D. D. Montgomery. *Rev. Scient. Instr.*, **10**, No. 11, pp. 350–352, November, 1939.
21. Fast Neutron Measurements with Recoil Counters—S. A. Korff. *Phys. Rev.*, **56**, No. 12, pp. 1241–1242, December 15, 1939.
22. Studies of Cosmic Rays—T. H. Johnson. *Carnegie Institution Year Book*, No. 38, 1938–1939, pp. 341–344, December 15, 1939.
23. Cosmic-Ray Investigations—S. A. Korff. *Carnegie Institution Year Book*, No. 38, 1938–1939, pp. 344–346, December 15, 1939.
24. Solar Influences on the Cosmic-Ray Intensity at High Elevations—S. A. Korff. Jour. Frank. Inst., **229**, No. 1, pp. 21–27, January, 1940.
25. The Instability of the Meson—M. A. Pomerantz. *Phys. Rev.*, **57**, No. 1, pp. 3–12, January 1, 1940.

25A. The Design and Construction of a Mercury Vapor Rectifier Tube—A. J. Allen and A. G. Nester. *Rev. Scient. Instr.*, **11**, 43 (1940).

26. The Contribution of Showers to Coincidences Recorded at High Elevations—T. H. Johnson and J. G. Barry. *Phys. Rev.*, **57**, No. 3, pp. 245–246, February 1, 1940.
27. Report on the Work of the Bartol Research Foundation, 1938–39—W. F. G. Swann. Jour. Frank. Inst., **229**, No. 3, pp. 281–335, March, 1940.
28. On the Interpretation of Neutron Measurements in Cosmic Radiation—H. A. Bethe, S. A. Korff, and G. Placzek. *Phys. Rev.*, **57**, No. 7, pp. 573–587, April 1, 1940.
29. Some Effects of Variable Excitation on Synchronous Motor Oscillation—J. G. Barry. Jour. Frank. Inst., **229**, No. 4, pp. 491–512, April, 1940.
30. Shower Production by Mesotrons in Different Materials—W. F. G. Swann and W. E. Ramsey. *Phys. Rev.*, **57**, No. 8, p. 749, April 15, 1940.

Papers Presented at Various Meetings

Presented before:

American Geophysical Union, Washington, D. C., April 26–29, 1939.

New Evidence of the Nature of the Primary Cosmic Radiation—T. H. Johnson.

Paper No. 24.*

New Evidence of the Nature of the Primary Cosmic Radiation—T. H. Johnson.

The Occurrence of Slow Mesotrons—C. G. Montgomery, W. E. Ramsey, D. B. Cowie, and D. D. Montgomery. (Published under title given in No. 12.)

The Contribution to the Soft Component of the Cosmic Radiation by the Disintegration of Mesotrons—M. A. Pomerantz and T. H. Johnson.

American Physical Society, Princeton, N. J., June 23–24, 1939.

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* In this section, papers which have also been published in full are indicated by the numbers referring to them, and corresponding to previous section.

American Physical Society, Washington D. C., April 27–29, 1939.

V.2
194

Paper No. 8.

Evidence for Neutrons in the Cosmic Radiation—S. A. KORFF.

The Nature of Cosmic-Ray Phenomena at High Altitudes—W. F. G. SWANN.

Cosmic-Ray Symposium, University of Chicago, Chicago, Ill., June 27–30, 1939.

Papers No. 15, No. 16, No. 17, No. 18.

International Congress for Unity of Science, Harvard University, Cambridge, Mass., Sept. 3–9, 1939.

The Significance of Scientific Theories—W. F. G. SWANN.

1939 International Congress of Biophysics, Biocosmics and Biocracy, New York, N. Y., Sept. 11–16, 1939.

Can Modern Science Harmonize Physics and Biological Phenomena?—W. F. G. SWANN.

American Philosophical Society, Philadelphia, Pa., November 17–18, 1939.

Paper No. 17.

American Physical Society, New York, N. Y., February 22–24, 1940.

Paper No. 26.

The Production of Neutrons in Cosmic-Ray Showers—S. A. KORFF.

Discharge Mechanism of Geiger-Mueller Counters—C. G. MONTGOMERY AND D. D. MONTGOMERY.

The Difference in the Meson Stopping Power of Lead and Water—M. A. POMERANTZ.

The Measurement of Discharge Characteristics of Geiger-Mueller Counters —W. E. RAMSEY

Wilson Cloud Chamber for Cosmic Rays—R. P. SHUTT.

Paper No. 30.

ADDRESSES PRESENTED BEFORE INSTITUTIONS, ETC.

Presented before:

Mount Holyoke College, South Hadley, Mass., May 2, 1939.

Science and Civilization—W. F. G. SWANN.

Explorers Club, New York, N. Y., May 9, 1939.

Side-lights of an Eclipse Expedition—S. A. KORFF.

Franklin Institute, Philadelphia, Pa., June 20, 1939.

Cosmic Rays as Atom Smashers—S. A. KORFF.

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THE BREAKING THEORY OF DETONATION.

BY

LEROY R. CARL.

PART II.

(*Concluded.*)

SUMMATION AND RECAPITULATION.

1. Molecules and crystals may in many ways be considered as identical.

2. They have definite form and are bound together by valence forces which cannot be explained otherwise than as *directed* forces.

3. That compounds may be classified as exothermic and endothermic, depending on whether energy is absorbed or released when the valence bonds are broken.

4. The condition of the endothermic compound is best described by assuming that the valence bonds are bent away from their natural direction with a resulting strain within the molecule or crystal. These compounds have within themselves a force tending to self-destruction. One compound may have both endothermic and exothermic bonds.

5. The form and the other properties of a compound are interdependent. The destruction of the form simultaneously destroys all of the properties, or the compound itself.

6. Crystals may be mechanically stressed to the point of rupture.

7. Crystals break under stresses which are only a small percentage of the theoretically calculated requirements.

8. Most crystals found in nature are imperfect.

9. Crystals have fissures or small cracks, in their surfaces, which is the probable cause of their low actual strength.

10. The surfaces of all crystals are unsaturated. The surface cracks or fissures are probably caused by the unsaturated condition or surface tension.

11. Strains in crystals disappear with the velocity of sound upon the release of stresses.

12. Sound waves distort solids mechanically and progressively.

13. Vibrations die, or are damped out, more rapidly in heterogeneous materials or imperfect crystals.

14. Materials may be broken by stresses all of which are compressions and in which all of the strains are a shortening.

Now taking into consideration the data quoted and presented in regard to the nature of (1) Molecules, (2) Crystals, (3) Some properties of heterogeneous bodies, (4) The effect of the application of stresses to these materials, (5) The effect of certain conditions on breaking and (6) The nature of sound, it is desired to state as concisely as possible, the writer's idea of the nature of the phenomenon known as detonation.

THEORY.

1. It (detonation) is the progressive breaking of the valence bonds of a material, by a stress which is transmitted through the material as an elastic wave, similar to a sound wave. This wave may be considered a sound wave of such intensity as to destroy the structure of the material. The fact that the structure of the material is destroyed brings into view the main distinction from the ordinary sound wave. That distinction is the fact that the to-and-fro movement experienced by the particles during the passage of a sound wave is prevented. The reciprocal or return motion of the particles carried forward by the wave in detonation is prevented by the break-down or collapse of the material, and by the extremely high pressure produced, behind the crest of the wave * by the recombination of the elements, which had constituted the explosive.

2. The transmission of such a stress will depend on the elastic nature of the material, in the same way that the transmission of sound, depends on that quality. The optimum condition for the transmission of the breaking wave is, therefore a material which is perfectly elastic, and which requires, only a slight distortion to cause a break-down. A perfect crystal supplies the nearest approach to these qualities. A

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* Reference should be made to the words of Jones at this point, "Then with a compression in front of it and a rarifaction behind it the layer of air is brought to rest and may even be started to move backwards."

condition which will tend to prevent the transmission of sound will have the same tendency toward detonation. Materials which are soft, plastic or fluid tend to damp out elastic waves and have a similar tendency with detonation.

3. The energy which maintains the breaking wave is the release of gases and heat, behind the wave crest, so that it is a continuous compression, instead of the compression and rarification of the ordinary sound wave.

4. The source of such a breaking stress may be the release of strains already existent, in the materials, nevertheless, some assistance, from an outside force is usually required.* Such strains exist in the endothermic compounds which have inherent internal instability. Most initiating or primary detonating compounds belong to this class. They are the rare materials which are absolutely necessary for the utilization of the common high explosives. The initiating impulse, for this type of compound may be a rise of temperature, impact, friction, the breaking of a crystal, or even allowing the surface to become dry. This last manner of initiation, is probably due to the unsaturated nature of the surface, and the fact, that the water or other liquid acts to reduce the sensitiveness by satisfying the unsaturated surface valencies.

5. Such a destructive stress may be applied to any material, but will be transmitted to but a limited extent in materials which do not release energy in sufficient quantity or intensity to maintain it.

6. The stress which is transmitted and which causes the disruption of the material is not the explosion, nor the direct cause of the explosion, but merely the disturbance, which releases the union between the atoms of the explosive compound, thus allowing them to recombine, in a more stable form, with release of energy. In this release is found the distinction between the endothermic and the exothermic compounds. The endothermic compounds possess a large part of their energy in their structure, and therefore, release

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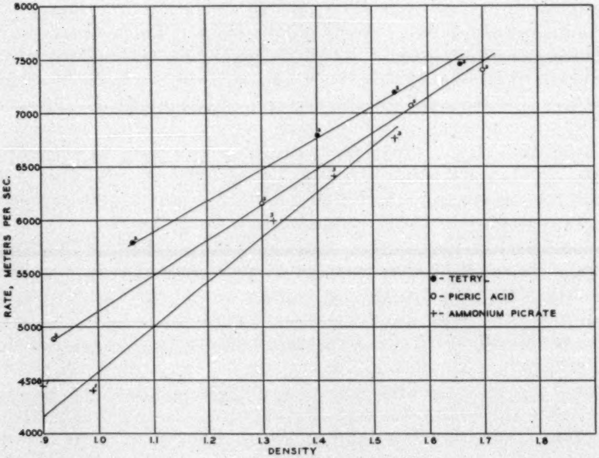
* "Probably the majority of chemical reactions, even those which eventually lead to the evolution of large amounts of energy, require some initial excitation of the molecule, and it undoubtedly frequently happens that a system must be lifted far above its original energy level before it can fall into a still lower energy level." "Valence and the Structure of Atoms and Molecules," Lewis, page 160, Reinhold Publishing Co., N. Y.

the energy of structure almost instantaneously upon destruction of the form. This is the characteristic which makes them effective as initiators of detonation. The exothermic compounds, on the other hand, require the expenditure of energy for the destruction of their form and derive a larger proportion of their energy from the recombination of their elements in the more stable condition.

7. The speed of the breaking wave has no relation to the violence of the reaction which follows. The speed of the wave is, mainly, controlled by the physical condition of the medium, in the same way as the rate of sound is determined by the physical constants. Extreme violence of reaction, following the wave, may cause a somewhat higher rate, in the same way, that the rate of a very intense sound wave, is increased above normal sound velocity. The violence of the reaction, following the wave, is dependent almost entirely upon the chemical nature of the material, left by the wave, or the products of *detonation*. The products of detonation must

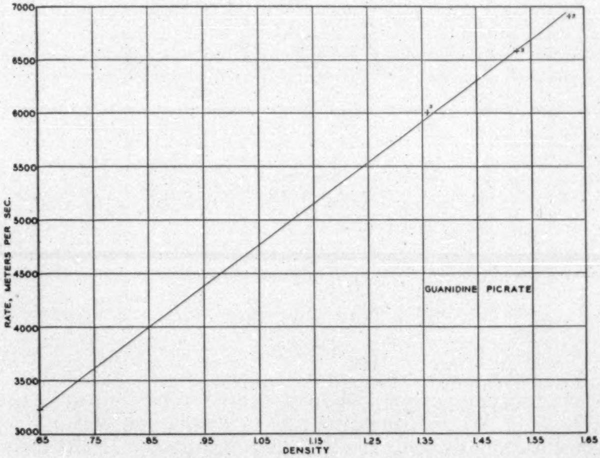
FIG. 5.



be definitely distinguished from the final products which result from the completed reaction, and which should be known as the products of explosion.

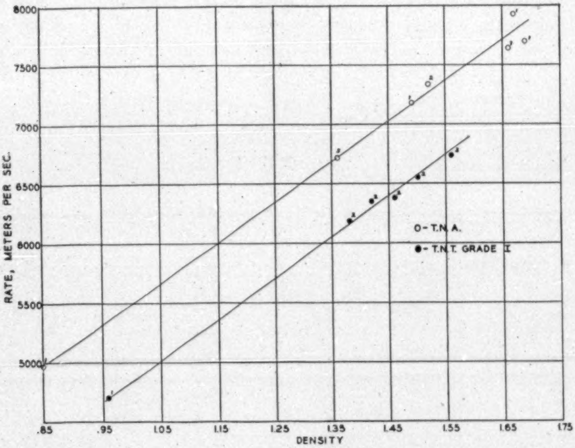
8. The distortion which brings about the breaking, carries a portion of the material forward and because of the intense pressure generated behind the wave, the reciprocal movement of the medium is prevented. This forward movement of the medium and the prevention of the counter-movement serves to increase the speed of the wave front. This effect explains the fact (which will be shown in experimental data) that the rate of detonation increases more rapidly with increase of density, in an insensitive than in a sensitive explosive. The insensitive material must be distorted and moved forward, to a greater extent, than the sensitive material, before rupture occurs.

FIG. 6.



It will be noted, in the Figs. 1, 5, 6, and 7 that the rates of detonation are plotted against density and approximate a straight line curve quite well, when the interfering factors are considered. Among the interfering factors, which have been mentioned, are: the impurity of the explosives; confinement; the effect of differing granulations; insensitive materials; and the stresses set up, within the crystals, by the high pressures, required to attain high densities.

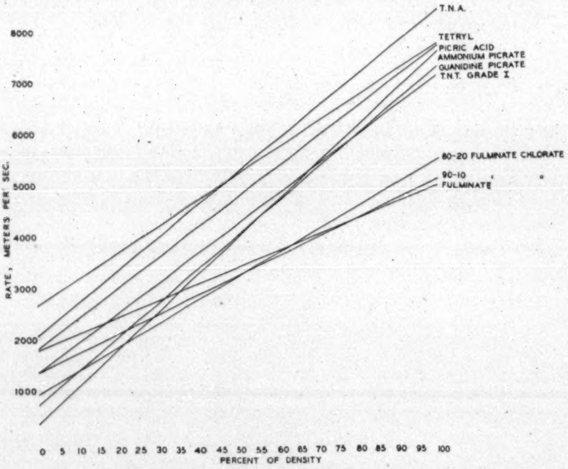
FIG. 7.



Now we will arrange the data given in Figs. 1, 5, 6, and 7 in a more fundamental manner to give them a greater significance. We will plot the rate of detonation, against the percentage of absolute density, extrapolating to zero density. The result is shown in Fig. 8. In Fig. 8 one fact stands out, i.e. that the sensitive explosives have the lowest rate of increase of rate, with increase of density. The distortion of the crystal lattice must be greater, in the insensitive compounds, before detonation occurs. This moving forward of the explosive at the passage of the wave, has been referred to in the discussion of the difficulties encountered in determining the rates of detonation with the explosive confined in steel tubes. The fact was noted, that good insulation was not effective to prevent the measuring wires being shorted to the tubes, but that insulation was made effective by increasing the diameter of the holes in the steel tubes to one quarter inch.

It is undoubtedly true, that the rate of sound, through explosive materials, plotted against density, can be represented as a straight line curve. There are, then, two factors acting to cause higher rates of detonation at higher densities: first, the increased rate of sound at higher densities and, second, the effect of the distortion of the material, which causes the explosive to move in the direction of the progress of the wave, thereby advancing the wave by a definite increment, which varies with each explosive. The forward movement of the material due to the distortion of detonation differs from that produced by sound by being a non-reciprocated movement. The molecules have collapsed and the energy for the continuation of the wave is furnished by the gases and heat liberated by the break-down or by the recombination of the elements after the break-down.

FIG. 8.



Therefore the formula for the straight line representing the rate of detonation can be written:

$$y = (a + a')x + b,$$

a, representing the constant by which the rate of sound increases, with increased density,
a' representing the constant by which the collapse of the molecule increases the rate through the explosive.

It will be noted, therefore, that in order to arrive at the exact sensitiveness value, a' (the amount by which the explosive material is deformed before break-down), the rate of sound must be determined through each explosive, at several densities, so that the value of a may be determined and subtracted from the quantity $(a + a')$. Nevertheless, the value $(a + a')$ is sufficiently significant to distinguish the sensitive from the insensitive explosives.

In Table 3 are given the values of the constants of the curves for the different explosives.

TABLE 3.

This table shows the constants for the curves, representing the rate of detonation plotted against percentage of specific gravity, for the explosives in Fig. 8. Formula for the straight line: y equals $(a + a')x + b$, y equals rate of detonation, $(a + a')$ and b are constants.

Explosive.	Value of $(a+a')$.	Value of b.	Approx. Sp.Gr. of Explosives.
Ammonium picrate	71.82 M./sec.	380 M./sec.	1.71
Guanidine picrate	65.33 M./sec.	735 M./sec.	1.70
Tetra-nitro-aniline	62.93 M./sec.	2065 M./sec.	1.84
Picric acid	58.52 M./sec.	1815 M./sec.	1.76
Tri-nitro-toluene	57.34 M./sec.	1365 M./sec.	1.65
Tetryl	50.17 M./sec.	2685 M./sec.	1.72
80–20 Fulminate-chlorate	45.40 M./sec.	940 M./sec.	4.00
90–10 Fulminate-chlorate	37.34 M./sec.	1365 M./sec.	4.21
Mercury fulminate	31.91 M./sec.	1795 M./sec.	4.42

The approximate specific gravity given in this table is taken as 100 per cent density in Fig. 8.

A few of the consequences of the acceptance of the breaking theory of detonation are:

1. That sensitivity is the most outstanding quality (Sine qua non) of explosives. That this quality can be most de-

finitely correlated with the rate of detonation and that sensitivity to detonation is very definitely affected by the following factors:

A. Perfect crystals and other nearly perfectly elastic materials are the most susceptical or sensitive to detonation and propagate the wave with the closest adherence to the straight line curve.

B. Materials which form long and complex molecules resist the initiation and propagation of detonation. These materials often exist as colloidal gels which are plastic and are often tough.

C. Small amounts of impurities, held within the crystals, have a great effect on sensitivity. This effect will be modified by the nature of the impurities and their effect upon the physical character of the crystals rather than by a diluting effect.

D. The condition of the surface of materials may decidedly influence their sensitivity to detonation. A very thin film which adheres to the surface, although extremely small in percentage, will change the entire character of an explosive. Besides protecting the surface such a condition will have a tendency to increase the mobility of the individual particle and to cause plasticity in some materials.

E. That liquids resist detonation. This is because they lack rigidity. However, the true sensitivity of such materials becomes evident when they are held as a thin film on a solid material, so that their mobility is decreased. In such a state they probably have definite orientation of the molecules.

F. That compounds may be classified as exothermic and endothermic. That the sensitivity of the two classes are radically different. That the sensitivity of crystals is primarily due to two types of instability. The first type of instability which is possessed by both types of compounds, is the surface instability. This instability has been shown to reduce the actual strength of crystals, to about 1/500th of the theoretically calculated value. The other type of instability is that possessed by the endothermic materials, only, and is the internal strain discussed by von Baeyer. We may say that both types of compounds have external weakness (surface unsaturation); while one, also, has inherent internal weakness (endothermic compound), and the other has inherent internal strength (exothermic compound). This causes them to react oppositely to certain changes. For instance, increased crystal size causes increased sensitivity in endothermic compounds and decreased sensitivity in exothermic compounds. The destruction of the crystal form of endothermic compounds, is accompanied by an instantaneous release of energy, and for this reason, most initiators of detonation, which go readily from ignition to detonation, belong to this type.

2. That the power and shattering effect of explosives does not depend upon the rate of detonation. These two characteristics can probably better be accounted for by the proper evaluation of the two types of energy released; the energy of formation and the energy by recombination. The quickness of the release of the energy of recombination is undoubtedly very dependent upon the reactivity of the reacting materials or "products of detonation." An explosive such as T.N.T. which has a deficiency of oxygen will not be so violent in action as one like nitroglycerine which has an oxygen excess.

3. That the effect of the total heat of explosion does not show the nature of the explosive. The energy derived from the heat of formation and that derived from the recombination of the products of detonation must be definitely segregated.

4. The different valence bonds of the same compound may be of different sign in respect to their heat of formation. When one calculates the effectiveness of potassium chlorate, for instance, its heat of formation should be figured from potassium chloride and oxygen, which is probably the only bond broken when this material is used as an explosive.

5. That most crystals are imperfect and that any physical change or treatment to which they are subjected will greatly influence their sensitivity. The application of high pressure or high temperature will set-up or releave stresses within the crystals which will profoundly effect sensitivity, and rate of detonation.

6. Any worth while study of detonation, from a theoretical point of view, must start with the crystal in the most perfect form obtainable. By such a study the fundamental nature of the laws governing this phenomenon may be greatly advanced.

As has been emphasized throughout this paper, the materials which conform most perfectly to the law of detonation are the regular crystals. Regular crystals will, therefore, be taken as the ideal or standard material from which all others deviate, causing less perfect adherence to the law of detonation. This means that all other materials, and even crystals which are not perfect, will be less sensitive and will transmit the wave less perfectly.

It is believed advisable to digress, at this point, for a few remarks about elasticity, plasticity and fluidity, properties which are difficult of definition, but which are important for the transmission of elastic waves. "The most important property by which all regular crystals are distinguished from amorphous substances is elasticity." [27] In crystals rupture occurs before an essential deviation from Hooke's law can be noticed. Bancroft says,[28] "Sealing wax is brittle if the pressure is applied rapidly, but is plastic if the rate of deformation is slow." And the same author says, "A material is brittle when a slight permanent deformation involves sudden rupture and when impact produces shattering" and "A material is tough when the resistance to deformation is marked, but permanent deformation does not involve rupture; and when the resistance to rupture on impact is marked." Nernst [27] says, "Since amorphous bodies (such as glass) show rigidity it would follow from this hypothesis that ordinary liquids, and even gases, must also, though to a very slight extent; so far this has not been proved possibly owing to the extreme smallness of the property." These terms are all relative and are somewhat summerized by Bingham.[29] "As a matter of fact we are forced to regard elasticity as a property which is entirely independent of fluidity and plasticity. . . . To measure the elastic deformation in either solids or fluids it is necessary to choose a time before the energy stored up as elastic deformation has had time to dissipate itself appreciably as viscous or plastic flow." These statements indicate that all materials are somewhat elastic, however the plastic and fluid materials require that the energy be applied in a more or less special way in order to cause it to react elastically, otherwise the energy will be dissipated as plastic or viscous flow. All plastic and fluid materials, because of this requirement will have a tendency to damp out elastic waves and will, therefore, have the same tendency toward detonation.

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[27] "Theoretical Chemistry," 5th Eng. Ed., Macmillan and Co. Ltd., London, pages 98 and 105.

[28] "Applied Colloid Chemistry," 1932, McGraw-Hill Book Co., N. Y., page 191.

[29] "Colloid Chemistry," Alexander, Vol. 1, 1926, Reinhold Publishing Co., N. Y., page 723

It must be kept in mind in the following discussion, that as detonation has been described as a breaking of the crystal or molecule by distortion by a stress transmitted as an elastic wave, that any agency, force or quality which protects or supports the crystal or molecule; increases the strength of the crystal or molecule; or which tends to prevent the transmission of stresses by elastic waves; will cause the materials to be less sensitive to detonation. This means that, it will not only be more difficult to initiate detonation, but that there will also be a tendency for the wave to be damped out after initiation.

A few of the agencies or qualities by which the crystal or molecule may be protected or supported are: a resistant container, high density of charge, mutual support by intertwined crystals, and toughness, such as that of colloidal gels. Another manner in which the material is protected is by being able to avoid the stress. This occurs in materials in a soft, plastic or fluid condition. Increase in the strength of the crystal or molecule may be due to three main causes; impurities in the crystal, plastic deformations,[30] and protection of the surface by satisfaction of the unsaturated surface valencies. We may say that all of these effects, whether it is support of the material, increase of the strength of the material, or the prevention of the effective transmission of stresses, tend to bring about the same final result, i.e., to prevent the destruction of the molecule, by a stress which is transmitted as an elastic wave.

From this point onward specific materials will be considered and the role of their qualities, which tend to condition sensitivity will be discussed.

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[30] "The Physics of Crystals," Joffe, page 56, "As has been already stated, the process of a plastic deformation increases the strength many times."

It is well known that gelatin dynamite will detonate at a rate of approximately, 7500 m./sec., when an intermediate charge, consisting of a half cartridge of straight dynamite, is used between the detonator and the gelatin. However, the same material detonates with a rate of only 2000 m./sec. when initiated by a detonator only. The higher rate may result from the fact, that rubber-like materials have different elastic characteristics toward stresses of different frequencies. This has been shown by the fact that sound has different velocities at different frequencies, in such materials. The application of the force on a large area of the explosive charge may cause the force to be more effective by allowing less chance for the molecules to escape or "dodge." Houwink[31] considers such materials when he says, "A third factor which may prevent the existence of brittleness in a substance is the presence of strong bonds *next* to weak ones. Examples of this are met in the case of textile stuffs and rubber. The great tensile strength here may be connected with the length of the chains, ... Such a fibre is not however brittle, since when an energy blow is received each main valence chain can easily 'dodge' and thereby cause the energy to be taken up immediately *over a large surface*."

Another example of resistance to detonation caused by the colloidal condition, is that of the dense type of smokeless powder. It is almost impossible to detonate such a material. A study of the nature of gels will readily show that such a condition can be expected, when it is known that gelatine which has absorbed its maximum amount of water when placed on a glass plate, upon drying, may break the glass, or even pull pieces of the glass from the surface. This is a case of extreme toughness. The resistance to deformation is great and permanent deformation does not involve rupture. The compressibility of gels is also much greater than that of other solids, and this, also, will tend to reduce the sensitivity, by allowing the material to escape the shock.

A comparison of cast and granular T.N.T. shows that there is a greater difference between these two forms of the same material than that found between two different explosives of very diverse composition. It is well known that mercury fulminate will not detonate cast T.N.T., whereas in the granular condition, detonation is initiated reliably. Even the largest detonators are not effective to detonate the cast material but when a booster charge is applied to a large area detonation is consistently initiated. It is probable that the cohesion of the mass, and the mutual support of the crystals requires that a certain minimum area must be acted upon to secure a sufficiently sudden crushing of the crystals. The rate of detonation of cast T.N.T. is somewhat lower than that of the granular material, also. It is probable that the binding material between the larger crystals of cast T.N.T. is in a colloidal condition, and that there is, therefore, a tendency to damp out the wave.

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[31] "Elasticity, Plasticity and Structure of Matter," 1937, Cambridge Press, London, pages 71–72.

Mercury fulminate may be so highly compressed, that it will not go from ignition to detonation.* This is believed to be a case of mutual support of the crystals. Taylor and Rinkenbach [32] have shown an interesting example of mutual support of the crystals. They say: "The large matted crystals of silver picrate did not explode when the weight was dropped 110 cm., but when pulverized, a drop of only 34 cm. was sufficient to cause explosion." Stillwell [33] makes some pertinent remarks on this subject: "A sheet or thread made of short crystals in random orientation, however, is brittle because there is no reinforcement by interlocking of the crystals" and in another statement, "A sheet of high grade gelatin is pliable and not easily broken, but a film formed from gelatin which has been broken down by hydrolysis (i.e. the molecules shortened) is relatively brittle."

The unsaturated surface of all crystals is the cause of their low strength as compared to the theoretical strength. It is probable that the great strength and plasticity of the colloidal condition is partially due to the satisfaction of the surface or interfacial valencies, which are not directed forces and are, therefore, not disrupted by distortion, and allow plastic flow.

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* It is interesting to note, at this point, that the pressure required to bring about this condition is greater when the material is initiated by impact, than that required when initiation is by flame. This, again emphasizes, the greater effectiveness of mechanical over calorific disturbances, in causing detonation.

[32] JOURNAL OF THE FRANKLIN INSTITUTE, Sept. 1927, page 375.

[33] "Crystal Chemistry," 1938, McGraw-Hill Book Co., N. Y., pages 402–3.

Adam[34] says, "Gases are adsorbed on solids by interaction of the unsatisfied fields of force of the surface atoms of the solid, with the fields of force of the molecules striking the surface from any gas or liquid in contact with the solid. . . . In this way the free energy or surface tension of the solid surface is diminished, often probably to a small fraction of its original value." Therefore, the adsorption of a material on the surface (according to the theory of crevices) would cause an increase of the actual strength and a greater resistance or insensitivity to detonation.

Colloid studies have shown that when two granular materials are mixed, the finer one forms a coating over the coarser material. This can be demonstrated by the use of two materials of different colors. The material having the finer granulation will give its color to the mixture. The writer has made an experiment to demonstrate the effect of this action on detonation. Five per cent. of lead chromate was added to potassium chlorate, yielding a yellow mixture and indicating that the chromate adhered to the surface of the chlorate. One gram of this mixture was then added to four grams of mercury fulminate. This gave a 80–20 fulminate-chlorate mixture, which is a commercially used product, except that in this case, it contained 19 per cent. of potassium chlorate and 1 per cent. of lead chromate instead of 20 per cent. potassium chlorate. This material was loaded in the usual manner in compound detonators and was found to have lost its effectiveness as an initiator of detonation. It is believed that this effect is caused entirely by protection of the surface.

It has been found that tetryl will detonate with, as much as, 10 per cent. of stearic acid mixed with it. But if even 2 per cent. of stearic acid is added and the material is then raised to or above the melting point of stearic acid, and again cooled, the mixture becomes so insensitive that any ordinary means is insufficient to cause detonation. This is probably the result of a combination of causes among which are; protection of the surface, mutual support of the crystals, and increased plasticity.

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[34] "The Physics and Chemistry of Surfaces," 2nd Ed., 1938, The Clarendon Press, Oxford, page 252.

The effect of impurities will depend to a large extent on their physical qualities. The addition of even a large amount, of highly elastic material to an explosive, may increase the sensitiveness of the whole mass. This occurs when powdered glass is used in primer mixtures. However, if the impurity has a tendency to satisfy the surface valencies of the explosive, a desensitizing effect will result. An example of this is the use of ferric oxide, in very fine division, mixed with T.N.T. This is a standard method for producing an insensitive charge, and is used to test the effectiveness of detonators. The effect of impurities within the crystal, however, act by changing the physical qualities of the crystal. The imperfect crystals are less perfectly elastic and therefore, are less sensitive and transmit the detonation wave less perfectly.

The reasoning applied to fluidity will answer the question of the insensitivity of nitroglycerine in the liquid form, which is detonated with difficulty by means of a fulminate detonator immersed in the fluid. When, however, this material is spread as a thin film on a solid it is extremely sensitive to impact; equaling in this respect the most sensitive compounds known. Here we have a film of nitroglycerine changed only by the fact that its fluidity has been reduced. It is also readily detonated by the smallest detonators when in the condition of a dynamite. And here again we have the sensitive film of the high explosive adhering to the surface of the other ingredients. This is the case of an explosive diluted by a non-explosive to cause greater sensitivity. Such a result would seem to be paradoxical, but both as the thin film on a hard material and as in the dynamite the effect has been to decrease the mobility so that the molecules are more readily deformed to the point of detonation.

The fact has been mentioned that as the crystals of an endothermic compound become larger the material becomes more sensitive and as the crystals of an exothermic compound become larger the material becomes less sensitive. This condition would seem to be explained by the fact that the source of the instability of the endothermic compound is largely within the crystal, not on the surface. Such crystals are inherently unstable. Each cell of the crystal lattice has a force acting to distort itself to the point of destruction. These forces of the individual cell are cumulative, and therefore, the larger the number of cells in a crystal the greater will be the total force tending to self destruction. On the other hand the exothermic crystal is inherently stable, on the interior, and all of the cells of the crystal support or re-enforce every other cell, in a way similar to the condition found with materials at high density or with intertwined and matted crystals.

As the last phase of the breaking theory, it is desired to impress the fact that detonation (the progressive destruction of the crystal lattice by an elastic wave), is a universal phenomenon. That all materials may be thus destroyed.* The best material for a demonstration of such a change is one which can be handled and examined after the passage of the wave. Such a material is steel. Foley and Howell [35] have quoted authority to the effect that Neuman bands are mechanical twins produced by shock. They show that such bands are produced by detonating dynamite against pieces of steel. They also show that the number of twins depends somewhat upon the rate of detonation of the dynamite but not upon the amount of deformation of the metal. It is evidently not cold work which is responsible, but a wave of energy, which has traversed the metal and momentarily released the valence bonds. However, the distances [36] involved by the destruction are such that recombination takes place almost instantaneously. The distinction between the passage of such a wave through an explosive and through other materials is that in the explosive the recombination is to a new set of compounds, with the release of a more or less great amount of energy, whereas in the non-explosive the recombination is merely to the same compounds with somewhat changed crystal forms. As there is no release of energy in this process the effect does not penetrate to any great distance. Foley and Howell conclude, 1st. That the abundance of Neuman bands increases with the velocity of impact until it passes 2296 m./sec. beyond which no appreciable increase occurs. 2nd. That there is a decrease in the number of bands with the distance from the face of impact to the back of those specimens that were supported by a lead block. And 3rd. That the number of Neuman bands does not bear any apparent relationship to the amount of plastic deformation which has been caused by the impact. It would seem that a velocity of 2300 m./sec. is that which is effective to send a detonation or breaking wave through steel and that higher rates are not more effective. In this connection it may be noted that mercury fulminate at shaking density (Table 7, Introduction), having a rate of approximately 3000 m./sec., will not initiate detonation in T.N.T. Yet the same initiator is effective to do so with picric acid or with tetryl which have as high rates as T.N.T. and much higher rates than the initiating mercury fulminate. The case of the steel is somewhat similar, the steel requires a detonation rate of approximately 2300 m./sec. to be effective in breaking down its crystal structure. However, the steel probably transmits the impulse at a much higher rate, as do the picric acid and tetryl.

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* Has anyone noted the odor which is produced when some rocks are broken by a blow.

[35] Paper of the American Institute of Mining and Metallurgical Engineers, No. 1186-S, Sept. 1922.

[36] "The Physics of Crystals," Joffe, 1st Ed., 1928, page 44. McGraw-Hill Book Co., N. Y.

As further evidence that the valence bonds have been released, the writer has discovered specimens of metals which have been completely welded by the action of the detonation wave.

There is now, but one remaining phase to add to this exposition. That is, to suggest a program of investigation, which is indicated as rational, with the acceptance of the theory proposed in this paper. In such investigation the effect of all interfering factors should, as far as possible, be eliminated. The investigation should start with crystalline materials of high purity. Care should be exercised, to assure that the crystal size, of any one explosive, at the different densities is uniform. Residual stresses in the crystals should be reduced by an annealing process, and as little as possible confinement of the charge, should be used.

It is, of course, desirable to verify the proposition, that the rate of detonation, plotted against density is a straight line. It is, also, desirable to determine whether, in every instance, the steepness of the curve, representing the rates, plotted against percentage of density, can be taken as a measure of the relative sensitivity of the explosives. A third desirable investigation is the determination of the rates of sound through some explosive materials at various densities. Knowing the rates of detonation through the same materials, this would make it possible to differentiate, between the increment of increase of rate, which is due to the rate of sound (the quantity a) and the increment which is caused by the non-reciprocal movement of the explosive (the quantity a'). The results of such determinations would allow the exact evaluation of the quantity a', which is the *sensitiveness value* of the explosive.

Rates of detonation should be determined using endothermic compounds in both fine and coarse granulations. The same procedure should be carried out with exothermic compounds. This would show whether granulation has an opposite effect upon the two types of compounds. The isomers of some explosives such as those of T.N.T. and picric acid should be used in rate determinations. This would throw some light on the relative effect of chemical composition and physical state, and also on the relation between power and rate of detonation. Another research, which might entail some difficulties, is the determination of the rate through different axes of the crystal. This would require that the crystals be orientated in more than one direction in relation to the main axis of the charge. It is known that the elasticity of a crystalline material is different through different axes, and as a consequence the velocity of the detonation wave should have different values. Rates of detonation should also be determined on some compound which exhibits dimorphism, such as the two crystal forms of nitroglycerine.

The completion of the suggested experimental work should leave little doubt as to the validity of the breaking theory of detonation.

IN CONCLUSION.

A new theory has been proposed to clarify the phenomenon of detonation, based on the recent progress in the knowledge of crystal and molecular structure. The main contentions of the new theory are:

That detonation is the progressive breaking of the valence bonds of compounds, by distortions, transmitted as elastic waves. The resulting products of detonation recombine with release of energy which maintains the wave.

The materials which are most readily detonated and which readily transmit detonation are the truly elastic materials (regular crystals).

Sensitivity is the most inherent characteristic of explosives, and is conditioned by two types of instability; surface instability caused by surface unsaturation, and internal instability caused by internal unsaturation (endothermic compounds).

Any state of matter or agency which tends to prevent the distortion of the molecule or crystal, will also tend to reduce the sensitivity. Any state of matter or agency which tends to increase the strength of the crystal or molecule will also tend to reduce the sensitivity.

All materials which tend to damp out elastic waves will transmit detonation imperfectly.

The breaking or detonation wave may penetrate any material and may, therefore, be considered a universal phenomenon.

INDUCTANCE OF HOLLOW RECTANGULAR CONDUCTORS.

BY

THOMAS JAMES HIGGINS,

Purdue University.

In this paper we obtain the complete expression for the inductance per unit length of two parallel conductors, one the return for the other, the cross-sections being hollow rectangles symmetrically located with respect to one another as in Fig. 2. No such formula is to be found in the literature; yet because of the increasing use of these conductors as bus bars in generating plants, major substations, electric furnace installations, and the like, it is most desirable that it be known. It is assumed that the current density over the cross-sections is uniform and the conductors are non-magnetic and of such length that end effects are negligible.

It is well known that the inductance per centimeter of two parallel conductors satisfying the foregoing conditions is, irrespective of the shape of cross-section,

$$\text{(A)} \qquad L = 2 \log_e \frac{D_{ab}^2}{D_a D_b} \text{ abhenries/cm.,}$$

where D_{ab} is the geometric mean distance between the conductor cross-sections and D_a, D_b are the geometric mean distances of each conductor cross-section from itself. Hence, our problem is reduced to finding the logarithms of these quantities for the cross-sections in question.

The logarithm of the geometric mean distance D between two rectangular areas symmetrically placed as in Fig. 1 was given by Gray.[1] Errors in his expression for D were found, the correct formula [2] being

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[1] Gray, "Absolute Measurements," Vol. II, Part I, p. 302.

[2] Rosa, *Bulletin of the Bureau of Standards*, Vol. 3, No. 1, p. 6.

FIG. 1.

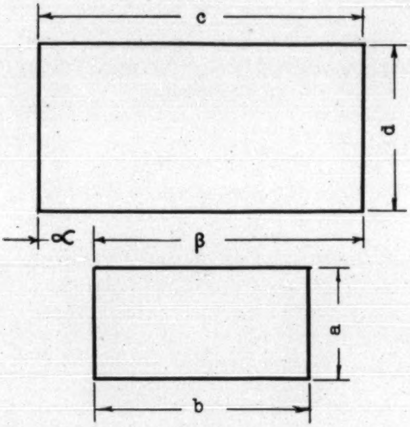
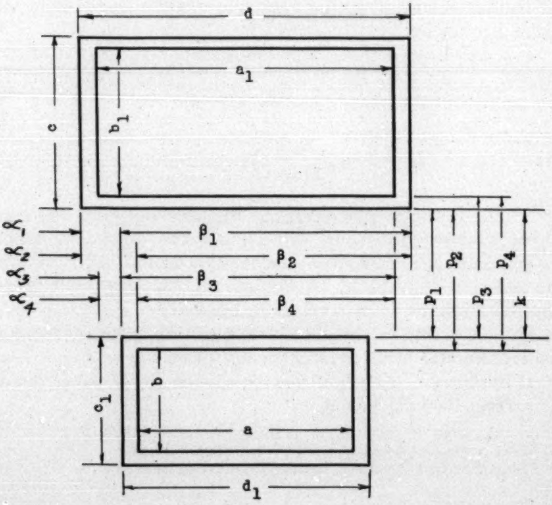


FIG. 2.


d
a_1
b_1
c
α_1
α_2
α_3
α_4
β_1
β_2
β_3
β_4
p_1
p_2
p_3
p_4
k
b
a
c_1
d_1

V.2
194

(1)
$$
\begin{aligned}
\operatorname{Log} D = \frac{1}{abcd}\Bigg[& \frac{1}{4}\left[(p+b+c)^2\left\{ \beta^2 - \frac{(p+b+c)^2}{6}\right\} - \frac{\beta^4}{6}\right] \log\left[(p+b+c)^2+\beta^2\right] \\
& - \frac{1}{4}\left[(p+b)^2\left\{ \beta^2 - \frac{(p+b)^2}{6}\right\} - \frac{\beta^4}{6}\right] \log\left[(p+b)^2+\beta^2\right] \\
& - \frac{1}{4}\left[(p+c)^2\left\{ \beta^2 - \frac{(p+c)^2}{6}\right\} - \frac{\beta^4}{6}\right] \log\left[(p+c)^2+\beta^2\right] \\
& + \frac{1}{4}\left[p^2\left\{ \beta^2 - \frac{p^2}{6}\right\} - \frac{\beta^4}{6}\right] \log\left[(p^2+\beta^2)\right] \\
& - (\text{the same series of terms with } \beta \text{ replaced by } \alpha) \\
& + \frac{\beta}{3}(p+b+c)^3 \tan^{-1}\frac{\beta}{p+b+c} + \frac{\beta^3}{3}(p+b+c)\tan^{-1}\frac{p+b+c}{\beta} \\
& - \frac{\beta}{3}(p+b)^3 \tan^{-1}\frac{\beta}{p+b} - \frac{\beta^3}{3}(p+b)\tan^{-1}\frac{p+b}{\beta} \\
& - \frac{\beta}{3}(p+c)^3 \tan^{-1}\frac{\beta}{p+c} - \frac{\beta^3}{3}(p+c)\tan^{-1}\frac{p+c}{\beta} \\
& + \frac{\beta}{3}p^3 \tan^{-1}\frac{\beta}{p} + \frac{\beta^3}{3}p\tan^{-1}\frac{p}{\beta} \\
& - (\text{the same series of terms with } \beta \text{ replaced by } \alpha) \\
& - \frac{(\beta^2-\alpha^2)}{8}\left\{(p+b+c)^2-(p+b)^2-(p+c)^2+p^2\right\} - \frac{11}{6}abcd\Bigg],
\end{aligned}
$$

where

$$\alpha = \tfrac{1}{2}(d-a) \qquad \text{and} \qquad \beta = \tfrac{1}{2}(d+a).$$

A cardinal theorem in geometric mean distance theory is the following: if $A_1, A_2, \cdots A_n$ are the components of a total area A, $R_1, R_2 \cdots R_n$ their respective mean geometric distances from a second area A', and R the geometric mean distance between A and A', then

(2) $$A \log R = A_1 \log R_1 + A_2 \log R_2 + \cdots A_n \log R_n.$$

Hence, referring to Fig. 2, we have by (2)

(3) $$c_1 d_1 \log D_1 = ab \log D_2 + (c_1 d_1 - ab) \log D_3,$$

where

D_1 = geometric mean distance between rectangular areas (cd) and (c_1d_1),
D_2 = geometric mean distance between rectangular areas (cd) and (ab),
D_3 = geometric mean distance between rectangular area (cd) and hollow rectangular area $(c_1d_1 - ab)$.

Therefore, by (3)

$$\log D_3 = \frac{c_1d_1}{c_1d_1 - ab}\log D_1 - \frac{ab}{c_1d_1 - ab}\log D_2. \tag{4}$$

Expressions for $\log D_1$ and $\log D_2$ can be obtained from (1) by substituting for the parameters as follows:

$\log D_1$	$\log D_2$
$\alpha = \alpha_1$	$\alpha = \alpha_2$
$\beta = \beta_1$	$\beta = \beta_2$
$p = p_1$	$p = p_2$
$a = d_1$	
$b = c_1$	

Substituting the resulting expressions for $\log D_1$ and $\log D_2$ in (4) we obtain for the logarithm of the geometric mean distance between a rectangular area (cd) and a hollow rectangular area $(c_1d_1 - ab)$ an expression

$$\log D_3 = f(\alpha_1, \alpha_2, \beta_1, \cdots c_1, d_1), \tag{5}$$

where, from the geometry of Fig. 2,

$$\begin{aligned} \alpha_1 &= \tfrac{1}{2}(d - d_1), & \alpha_2 &= \tfrac{1}{2}(d - a), \\ \beta_1 &= \tfrac{1}{2}(d + d_1), & \beta_2 &= \tfrac{1}{2}(d + a), \\ p_1 &= k, & p_2 &= k + \tfrac{1}{2}(c_1 - b). \end{aligned}$$

From (2) and (5) we can obtain the geometric mean distance between the hollow rectangular area $(c_1d_1 - ab)$ and the similar area $(cd - a_1b_1)$. By (2) we have

$$cd \log D_3 = a_1b_1 \log D_4 + (cd - a_1b_1) \log D_{ab}, \tag{6}$$

where

D_4 = geometric mean distance between the rectangular area (a_1b_1) and the hollow rectangular area $(c_1d_1 - ab)$,

D_{ab} = geometric mean distance between the hollow rectangular areas $(c_1d_1 - ab)$ and $(cd - a_1b_1)$.

Solving (6) for $\log D_{ab}$ we obtain

$$\log D_{ab} = \frac{cd}{cd - a_1b_1}\log D_3 - \frac{a_1b_1}{cd - a_1b_1}\log D_4. \tag{7}$$

The expression for $\log D_4$ can be obtained from (5) by letting the parameters of (5) take on the following values:

$$\begin{aligned} \alpha_1 &= \alpha_3, & a &= a, \\ \alpha_2 &= \alpha_4, & b &= b, \\ \beta_1 &= \beta_3, & c &= b_1, \\ \beta_2 &= \beta_4, & d &= a_1, \\ p_1 &= p_3, & c_1 &= c_1, \\ p_2 &= p_4, & d_1 &= d_1. \end{aligned}$$

Substituting for $\log D_3$ and $\log D_4$ in (7) we obtain for the logarithm of the geometric mean distance between two hollow rectangular areas $(c_1d_1 - ab)$ and $(cd - a_1b_1)$ an expression

$$\log D_{ab} = f(\alpha_1, \alpha_2, \alpha_3 \cdots c_1, d_1), \tag{8}$$

where

$$\begin{aligned} \alpha_3 &= \tfrac{1}{2}(a_1 - d_1), & \alpha_4 &= \tfrac{1}{2}(a_1 - a), \\ \beta_3 &= \tfrac{1}{2}(a_1 + d_1), & \beta_4 &= \tfrac{1}{2}(a_1 + a), \\ p_3 &= k + \tfrac{1}{2}(c - b_1), & p_4 &= k + \tfrac{1}{2}(c_1 - b) + \tfrac{1}{2}(c - b_1). \end{aligned}$$

Hence $\log D_{ab}$ is completely known in terms of the dimensions of the hollow rectangles and their distance apart.

To obtain the logarithm of the geometric mean distance of either hollow rectangular area from itself we need only let the parameters of (8) take on the following values:

$$\begin{array}{llll} & (c_1d_1 - ab) & & (cd - a_1b_1) \\ a = a & \alpha_1 = \alpha_4 = 0 & a = a_1 & \alpha_1 = \alpha_4 = 0 \\ b = b & \alpha_2 = -\alpha_3 = \tfrac{1}{2}(d_1 - a) & b = b_1 & \alpha_2 = -\alpha_3 = \tfrac{1}{2}(d - a_1) \\ c = c_1 & \beta_1 = d_1;\ \beta_4 = a & c = c & \beta_1 = d;\ \beta_4 = a_1 \\ d = d_1 & \beta_2 = \beta_3 = \tfrac{1}{2}(d_1 + a) & d = d & \beta_2 = \beta_3 = \tfrac{1}{2}(d + a_1) \end{array}$$

$a_1=a$ $\quad p_1=-c_1;\ p_4=-b$ $\qquad a_1=a_1$ $\quad p_1=-c;\ p_4=-b_1$
$b_1=b$ $\quad p_2=p_3=-\frac{1}{2}(b+c_1)$ $\qquad b_1=b_1$ $\quad p_2=p_3=-\frac{1}{2}(b_1+c)$
$c_1=c_1$ $\qquad c_1=c$
$d_1=d_1$ $\qquad d_1=d$

Assuming these values substituted in (8) we have expressions for the following:

(9) $\log D_a$: the geometric mean distance of hollow rectangular area $(c_1d_1 - ab)$ to itself, and
(10) $\log D_b$: the geometric mean distance of hollow rectangular area $(cd - a_1b_1)$ to itself.

Hence (A) is completely determined in terms of the dimensions and spacing of the hollow rectangular areas and our problem in its most general aspect is solved.

In practice the conductor cross-sections are usually identical and of uniform wall thickness (t). For this important case D_a and D_b are equal and (A) becomes

$$L = 2 \log \frac{D_{ab}^2}{D_a^2} \text{ abhenries/cm.,} \tag{A$'$}$$

where the logarithms involved can be most quickly obtained from (8) by assigning to the parameters the following values:

	$\log D_{ab}$	$\log D_a$
$a=a$	$\alpha_1=\alpha_4=0$	$\alpha_1=\alpha_4=0$
$b=b$	$\alpha_2=-\alpha_3=\frac{1}{2}(d_1-a)=t$	$\alpha_2=-\alpha_3=t$
$c=c_1$	$\beta_1=d_1=a+2t;\ \beta_4=a$	$\beta_1=a+2t;\ \beta_4=a$
$d=d_1$	$\beta_2=\beta_3=\frac{1}{2}(d_1+a)=a+t$	$\beta_2=\beta_3=a+2t$
$a_1=a$	$p_1=k;\ p_4=k+c_1-b=k+2t$	$p_1=-c_1;\ p_4=-b$
$b_1=b$	$p_2=p_3=k+\frac{1}{2}(c_1-b)=k+t$	$p_2=p_3=-(b+t)$
$c_1=c_1$		
$d_1=d_1$		

V.2
194

PHYSICAL AND ASTRONOMICAL INFORMATION CONCERNING PARTICLES OF THE ORDER OF MAGNITUDE OF THE WAVE-LENGTH OF LIGHT.*[1]

BY

FELIX EHRENHAFT, Ph.D.

I begin with a very simple problem (Fig. 1). Here you see a sphere of colophonium, photographed first in blue and then in ultra-violet light—absorbing the light in the first case, transmitting it and surrounded by a black diffraction-ring in the second case. What is the true size of the sphere? Does the diffraction enlarge the objects? To settle this question we use a micromanipulator to bring two spheres of equal size into contact (Fig. 2). The images overlap! and they overlap each other more, the smaller the spheres (Fig. 3). This experiment can be performed with spheres of radii as small as about 10^{-5} cm. Exact investigations have shown that the correct radius a of the sphere, and the magnification Δ, can be determined by two simple measurements: the apparent long and short diameters of the "double sphere" are ($4a$ plus 2Δ) and ($2a$ plus 2Δ) respectively (Fig. 4).

Such an experiment was done with two spheres of selenium, one of which had previously been allowed to fall in pure nitrogen at very high pressure (up to 20 atmospheres). The value of diameter obtained from the optical experiment

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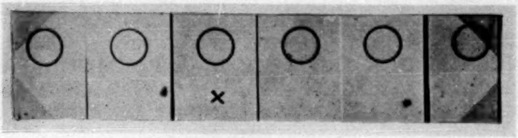
* *Editorial Comment.* While it is recognized that Professor Ehrenhaft's conclusions as to the significance of his experiments are highly controversial, the experimental results themselves are such as to have recently excited the interest of several prominent authorities. The present paper is published with a full recognition of these factors and without comment for or against the views expressed.

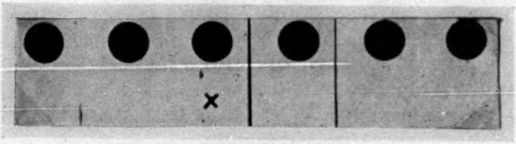
[1] Here I wish to thank Dr. Karl K. Darrow for his kind coöperation in translating this paper. (Presented at the meeting of the American Physical Society, New York, Feb. 24, 1940.)

I wish to thank Mr. George Altmann (Fordham University) and Baron Robert von Heine-Geldern, Jr., for thoroughgoing aid in compiling the literature; and most of all Prof. Dr. Janos Plesch (London) for facilitating continuation of my scientific work after I was forced to leave my institute and home in Vienna.

FIG. 1.

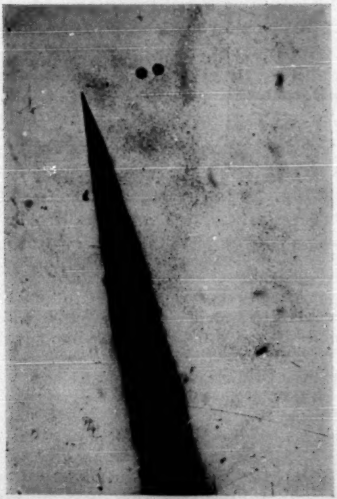


Colophonium
$a = 108.35 \times 10^{-6}$ cm.
$\lambda = 420$ mμ, Apochromate 10, n.A. = 0.30
Magnification about 412 times, plate No. B 167



Colophonium
$a = 108.35 \times 10^{-6}$ cm.
$\lambda = 275$ mμ, Monochromate 0.35, n.A. = 0.35
Magnification about 459 times, plate No. B 166

FIG. 2.

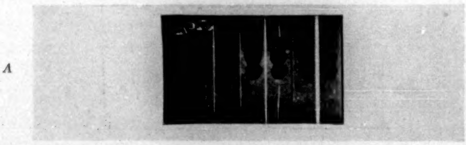


Point of micromanipulator and two spheres of red selenium before they are brought into contact.
Magnification about 2500 times.

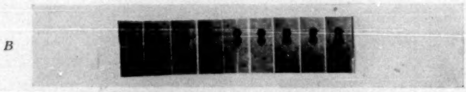
agreed with that obtained from the speed of fall by the use of Stokes' Law.[2] In the calculation by Stokes' Law, a value for the density of the sphere must be assumed. I assumed the value appropriate to selenium in bulk, and therefore the foregoing result may be regarded as a test, successful within 3

FIG. 3.

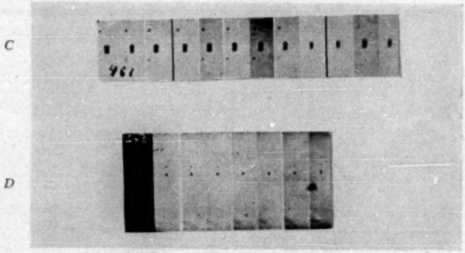
Particles of selenium brought into contact.



(*A*) True radius: upper sphere 19.56×10^{-5} cm.
lower sphere 20.83×10^{-5} cm.



(*B*) True radius: upper sphere 13.32×10^{-5} cm.
lower sphere 12.85×10^{-5} cm.



(*D*) True radius: upper sphere 3.05×10^{-5} cm.
lower sphere 3.02×10^{-5} cm.

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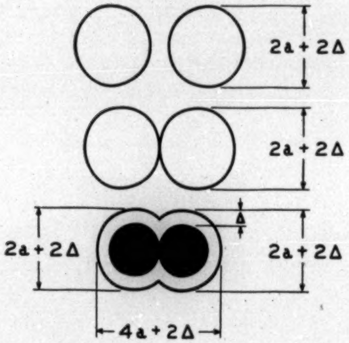
[2] Stokes' formula for the speed of fall of a particle in a sufficiently dense gas is as follows:

$$v_0 = \frac{2}{9} a^2 g \frac{\sigma}{\eta},$$

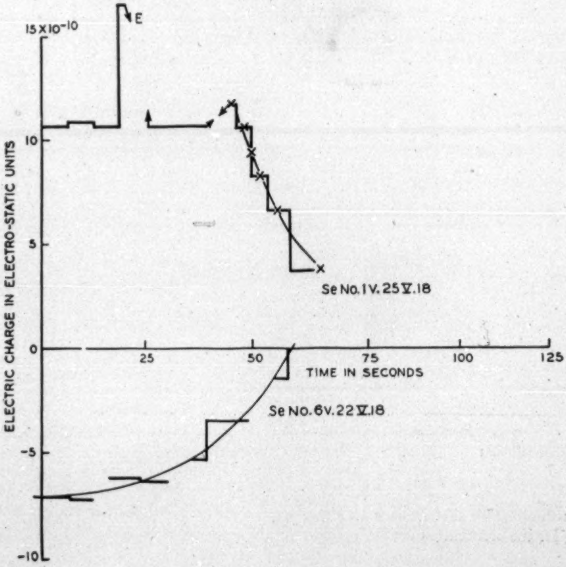
a standing for the radius, σ for the density, and v_0 for the speed of the particle; g for the acceleration of gravity and η for the viscosity of the gas.

FIG. 4.


2a + 2Δ
2a + 2Δ
Δ
2a + 2Δ
2a + 2Δ
4a + 2Δ

Determination of the size of spheres of diffraction discs.

FIG. 4½.



V.
19

per cent., of the assumption that these spheres have the normal density of selenium.[3] The agreement is within 3 per cent.

In my small horizontal condenser (diameter of plates 8 mm.) it is possible to compare the weight of a single charged sphere with the electric force acting upon the sphere, and therefore to determine the charge of the individual sphere without any averagings at all. I did this half a year earlier than the well-known oil-drop experiments done with condensers twenty times larger. I always found, and am still finding, charges smaller than the electron-charge. This result does not depend upon any assumptions whatever as to atomicity of matter or electricity.[4]

If the beam of light is strongly concentrated, it is observed that some of the spheres irradiated by it are moving towards and others away from the source of light (Fig. 5). I called this phenomenon "photophoresis"—"light-negative" and "light-positive" in the two cases.[5] Other investigators confirmed this result independently of me.

We must try first to interpret photophoresis by the older theories (Fig. 6).

The light-positive effect might be ascribed to light-pressure (Johannes Kepler, 1619). The influence of the gas must also be taken into account ("radiometer forces," Crookes, 1874). Ordinarily spheres are heated more strongly on the side turned toward the light, and yet the opposite can occur under certain optical conditions. The pressure of the gas would produce a light-positive effect in the former case, a light-negative in the latter. This might seem to be a sufficient explanation.

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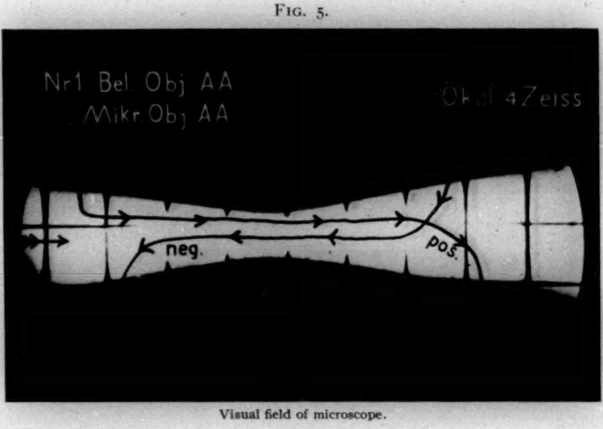
[3] The density of red amorphous selenium in bulk is 4.26, while the densities of the particles were found to be 4.31, 4.21, 4.39, 4.22, 4.19—mean value 4.26, greatest departure from mean 3 per cent.

[4] Be it further remarked that individual spheres of red amorphous selenium, kept floating in air for hours (in diffuse light or in no light at all) and having initially a charge of the order of 7 to 10 times 10^{-10} E.S.U., loose this charge in apparently continuous fashion. This loss of charge can be made to occur within a few minutes by using activated test bodies. Of course it is impossible in principal to make an experimental test between continuity and discontinuity, but it can be established with certainty that if the changes in charge are discontinuous, the discontinuities are smaller than e (Fig. 4½).

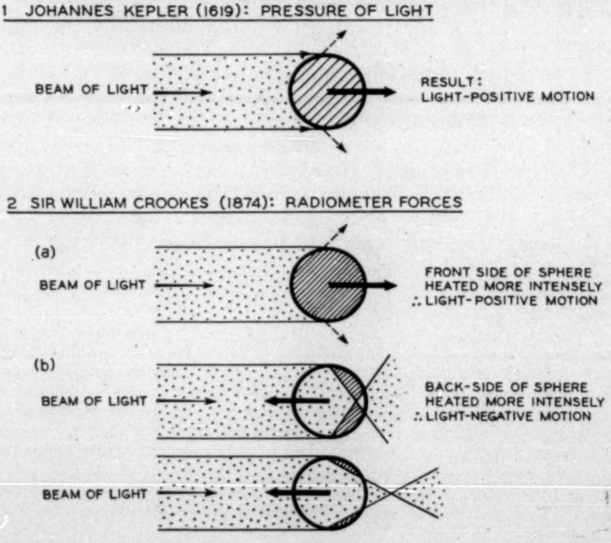
[5] The apparatus is so set up that the test body can be illuminated from the left, the right, or both sides, and the illumination from either side varied at will.

FIG. 5.


Nr1 Bel. Obj. AA
Mikr. Obj. AA
Okul 4 Zeiss
neg.
pos.

Visual field of microscope.

FIG. 6.


1 JOHANNES KEPLER (1619): PRESSURE OF LIGHT
BEAM OF LIGHT
RESULT:
LIGHT-POSITIVE MOTION
2 SIR WILLIAM CROOKES (1874): RADIOMETER FORCES
(a)
BEAM OF LIGHT
FRONT SIDE OF SPHERE
HEATED MORE INTENSELY
∴ LIGHT-POSITIVE MOTION
(b)
BEAM OF LIGHT
BACK-SIDE OF SPHERE
HEATED MORE INTENSELY
∴ LIGHT-NEGATIVE MOTION
BEAM OF LIGHT

However, shortly after the discovery of photophoresis, I assured myself that these forces do not suffice for the explanation. For instance, there are silver spheres which exhibit a tremendous light-negative motion, though as the most strongly reflecting of all substances silver certainly ought to be most heated on the side toward the light. Again it is known that selenium spheres of equal size in hydrogen, nitrogen and argon experience the same photophoretic negative force, though the conduction of heat and the gas-viscosity are very different in the three gases. Other examples could be cited for the same purpose.

Moreover, my pupil, the East Indian Satiendra Nath Ray has found that photophoresis is exhibited by particles suspended in liquids. W. W. Barkas, working in the London laboratory directed by Porter and Andrade, has shown that the great majority of gold, silver and copper particles are light-negative when in liquids, while oil-drops are mostly light-positive; and that the forces are of the same order of magnitude as those which I measured in gases. Now, the Crookes or radiometer forces cannot exist in liquids; if one assumed that they did, one would again arrive at conclusions opposite to the facts.

I therefore deduce that by the aid of light a kind of attractive forces can be exerted on matter in the direction toward the source of light. It is clear to me that these forces depend on the frequency of the light and on the nature and the geometry of the irradiated matter. Light in nature therefore is able not only to repel, but also to attract.[6]

Among the many striking phenomena which I have observed in connection with the "conflict of light and matter," including those occurring in electric and magnetic fields, there is one which I should like to mention.

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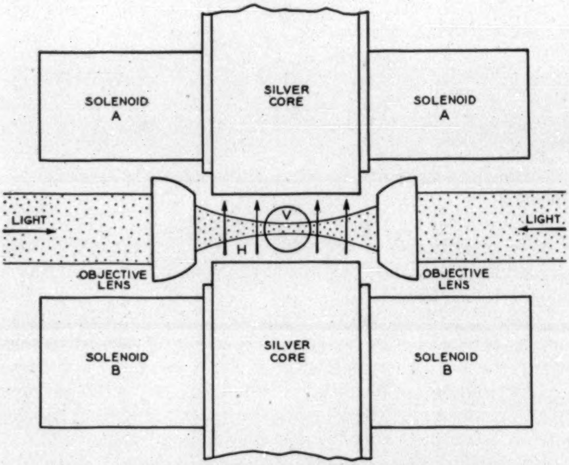
[6] In the known experiments on light-pressure the dependence of the effect on frequency of light and nature of the illuminated matter has never been sufficiently tested. It is impossible to separate the very small light-pressure from the large radiometer forces, and the degassing of the matter is very hard. Among the theoretical arguments for the existence of light-pressure I mention first of all the derivation of the Stefan-Boltzmann Law, which is based on such an assumption. The "perpetum mobile of the second kind" described by Eddi is impossible according to Bartoli, because of light-pressure. In the Maxwell theory and the electron-theory, light-pressure is simply assumed (law of conservation of momentum in electrodynamics: Poincaré, Max Abraham).

I set up a magnetic field—homogenous, commutable, and free of remanence—in my small condenser by means of suitable coils (Fig. 7). If in this apparatus e.g. particles of nickel are intensely illuminated, they move immediately in the direction of the magnetic lines of force, namely a part of them moves toward one pole, the rest toward the other one. When the field is commuted the direction of motion reverses. When either the light or the field is shut off, this motion ceases instantly and only the pure motion of fall remains. I have given the name "magnetophotophoretic force" to the force which is thus proved to act on matter when strongly illuminated and placed in a magnetic field. This force is proportional to the field strength for low fields, while at higher fields saturation occurs (Fig. 8). It is so great as to be operative in the magnetic field of the earth. From this it follows

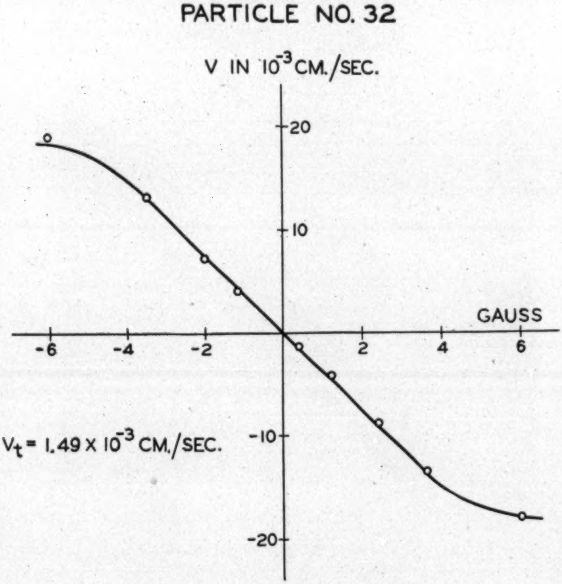
FIG. 7.


SOLENOID A
SILVER CORE
SOLENOID A
LIGHT
V
H
LIGHT
OBJECTIVE LENS
OBJECTIVE LENS
SOLENOID B
SILVER CORE
SOLENOID B

H VERTICAL—REVERSIBLE—HOMOGENOUS—MAGNETIC FIELD
V VISUAL FIELD OF MICROSCOPE, PERPENDICULAR TO LIGHT AND FIELD

that (to take an example) in the mighty magnetic fields of stars, matter must be driven by the photophoretic force to move in the direction of the magnetic lines of force. Now, the American Astronomer G. E. Hale has pointed out (without explaining) a similarity between the solar corona and the lines of force of a magnetized sphere. I consider it clear that the magnetophotophoretic force at the surface of the sun is propelling matter in the direction of the lines of magnetic force. Here is a picture by Hale; and a clearer relationship is shown by another picture (taken from *Mem. R. A. S.*, vol. 64) (Fig. 9), representing the corona as seen at the eclipse of May

FIG. 8 (1).



V_t velocity of fall, V proportional to the magnetophoretic force.

FIG. 8 (2).

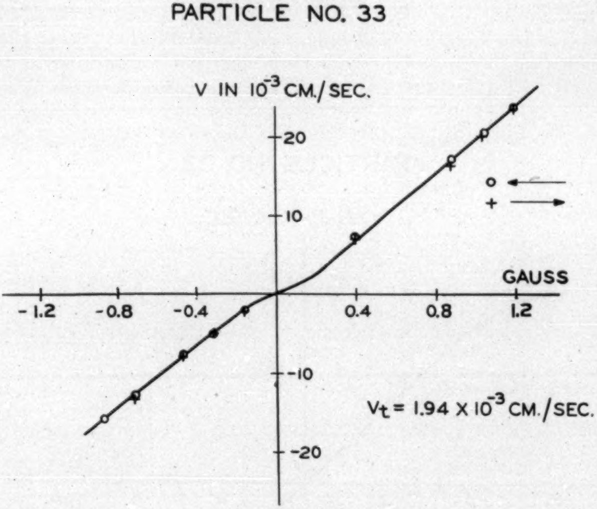
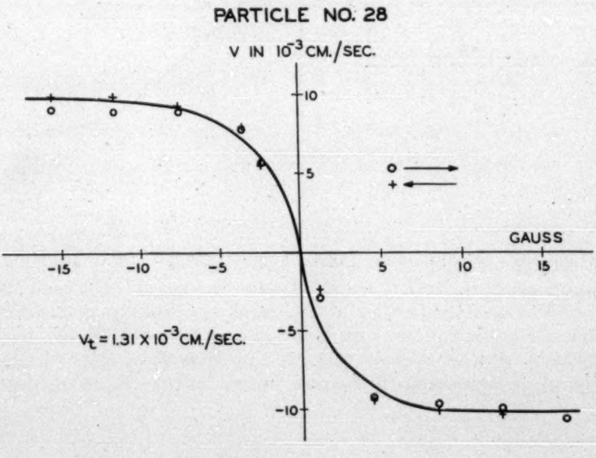

PARTICLE NO. 33
V IN 10^{-3} CM./SEC.
20
10
-10
-20
GAUSS
-1.2
-0.8
-0.4
0.4
0.8
1.2
o ←
+ →
V_t = 1.94 X 10^{-3} CM./SEC.

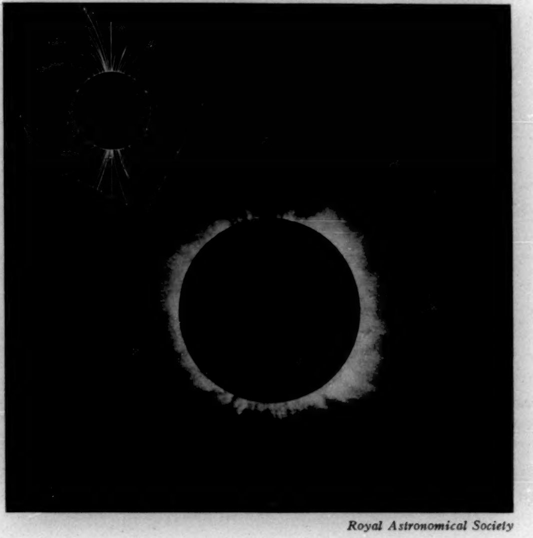
FIG. 8 (3).


PARTICLE NO. 28
V IN 10^{-3} CM./SEC.
10
5
-5
-10
GAUSS
-15
-10
-5
5
10
15
o →
+ ←
V_t = 1.31 X 10^{-3} CM./SEC.

28, 1900, from Omar in Portugal.[7] (There are also many other pictures of this kind.)

In conclusion let me summarize the facts I have observed and proved:

FIG. 9.



Royal Astronomical Society

(*a*) There exist charges smaller than the electronic charge on spheres whose sphericity and normal density is proved beyond doubt.

(*b*) Light not only can exert repelling but also a kind of attracting forces upon matter.

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[7] Spectroscopy teaches us that the solar corona in its upper regions consists of H, He, Ca, Fe, and Ni. The well known attempts to explain the puzzling shape of the corona and other astronomical phenomena by assuming a motion of charged particles under the sole influence of the Lorentz force do not agree with the facts.

(*c*) An intense beam of light makes bodies move in either direction of the lines of force of a homogeneous magnetic field as if they were single magnetic north or south poles.

According to the explanation given again in my paper appeared in Paris, April 1940, particles of matter move in a homogenous electric field only when under the influence of an intense beam of light as if those particles were carrying positive or negative electric charges (Electrophotophoresis).

Now I have shown that particles of matter move in a homogenous magnetic field in the direction of the lines of force when irradiated by an intense beam of light, as if they were carrying single magnetic north or south poles, respectively (Magnetophotophoresis). They behave like "magnetic ions."

But any motion of electric charges caused by an homogenous electric field is called an electric current.

Consequently a motion of magnetic poles caused by an homogenous magnetic field should be considered a "Magnetic Current."

Proof 1.—In my condenser (cf. Fig. 8 and my Paris paper in *Annales de Physique*, April 1940, where a diagram to scale is given) the beam of light together with a homogenous magnetic field produces such a magnetic current, where the particles behave like single magnetic north or south poles.

Proof 2.—In the universe: There exists under the influence of sunlight a magnetic current on the sun flowing from the sun to the earth, entering the magnetic field of the earth along its lines of force, mostly near the magnetic north or south pole of the earth (Polar light, effects of magnetic storms).

All those results and conclusions are based upon simple and easily reproducible experiments. I consider it impossible to come to different conclusions without violating the facts that can be observed at any time in my condenser.

I came to all these conclusions without any assumption whatever as to the quantization (atomicity) of electricity, matter or radiation.

It seems to me that with this I removed one of the fundamental differences between electricity and magnetism. They both must be different symptoms of the same natural phenomenon.

REFERENCES.

(*a*) Regarding the problem of charges smaller than the electronic charges, see *Phys. Zeitschr.*, **39**, 685, 1938.

(*b*) Regarding the photophoresis see "Photophorèse, Électrophotophorèse et Magnetosphotophorèse," *Annales de Physique*, Paris, **13**, 151, 1940. Old references: *Phys. Zeitschr.*, **31**, 478, 1930; **33**, 201, 1932.

(*c*) Regarding diffusion, Brownian movement, Loschmidt-Avogadro's number and light, in connection with magnetophotophoresis, see Phys. Rev. June 1, 1940; see also Phys. Rev. **57**, 562, 1940 and **57**, 659, 1940.

(*d*) Regarding magnetic currents: The author's latest paper, "Production of single magnetic poles by light (An hypothesis of magnetic ions and magnetic currents)," was sent to the Royal Society, London, late in March, 1940. This paper also deals with the apparent changes of poles (magnetic charges) on the test particles, moving between the "magnetrodes" in either direction. They behave analogous to electric ions in electric fields, changing their charges only when under the influence of a very low magnetic field or without any field at all, and are very rare with ferromagnetic particles and very frequent with diamagnetic particles. Whether such a magnetic current is surrounded by a constant electric field has yet to be investigated.

CATHOLIC COMMITTEE,
8TH AVENUE AND 14TH ST.,
NEW YORK CITY.

Radio for Parachute Fire Fighters Developed by U. S. Forest Service.—A new lightweight radio for the parachuting fire fighters being used on the National Forest for the first time this year was announced recently by the Forest Service, U. S. Department of Agriculture. Tests made by the Forest Service on the Chelan National Forest in Washington with a crew of parachute jumpers indicated the practicability of dropping fire fighters from airplanes to put out small fires in some of the inaccessible back country areas of the National Forests. The new radio-phone has been developed so that the smoke jumper can keep in touch with the plane pilot and with his headquarters when he reaches the ground. The smoke jumpers use a specially designed parachute which has a rate of descent of about twelve feet per second and permits a certain amount of steering toward the landing spot. A special chute harness and protective suit and headgear were also developed to so protect the jumpers that they can land almost anywhere at any elevation—in tall trees or open spaces, or on rough ridges. Planes which deliver the parachuting fire fighters scout the fire on their first trip over the spot and drop a small test chute with a ten pound sand bag to determine wind drift. Then they circle back and make a second approach, at which time the parachutest descends, and by using the steering flaps on his parachute, generally manages to reach the ground close to the selected landing spot. On a third approach the pilot drops the fire fighting kit which is carried down by a burlap chute with a yellow streamer attached to prevent its being lost—a method used by the Forest Service for some years to deliver tons of equipment to back country fire fighters. The burlap chute pack contains necessary tools, rations, first aid kit and the like but the parachutest will carry with him the new light-weight radio so that he can contact the pilot or his headquarters immediately if necessary or can make reports later. The small type radiophone developed by the Forest Service weighs only six pounds with dry batteries and all accessories and is not quite as large as a loaf of sandwich bread. It measures 2 by 4½ by 12 inches, and operates on ultra-high frequencies between 30,000 and 40,000 kilocycles, having a two-way communication range covering an optical distance which with sufficient elevation may be as much as a hundred miles. It is crystal controlled.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

IONOSPHERE STORMS AND RADIO TRANSMISSION BETWEEN NORTH AMERICA AND EUROPE.

A joint study of radio transmission, involving radio measurements in Argentina and the United States, coordinated with similar measurements in Europe, has been in progress since 1935. A paper on this subject, prepared jointly by A. T. Cosentino of the Ministry of the Interior, Argentina, and J. H. Dellinger, Chief of the Bureau's Radio Section, was presented at the Eighth American Scientific Congress in Washington last May. A remarkable anomaly in long-distance broadcast transmission had been indicated by certain observations in 1932, viz., much lower received wave intensities for transmission across the North Atlantic Ocean between Europe and North America than for transmission over the same distances within North America, Europe, or Asia. The present study was made to determine what happens on transmission paths between South America and the other continents, and has yielded an explanation of the North Atlantic anomaly.

The work was confined to the northern winters or southern summers because it is only at that time of year that there is an opportunity to make observations in the Americas on radio broadcasting from Europe. Radio transmission at broadcast frequencies occurs over great distances only at night, and it is only in December and adjacent months that there are periods when local interference is absent and night prevails throughout the region between Europe and eastern North America or Argentina.

The work has established the fact that radio transmission between South America and either North America or Europe is relatively free from influences that seriously impair transmission between North America and Europe. For the time of year at which the measurements were made (northern winter or southern summer), the received intensities for transmission between North America and South America average approximately 25 times the intensities between North America and Europe, and are only about 1/15 as variable.

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* Communicated by the Director.

The conditions of low and variable received intensity are characteristic of radio transmission over any path at times of ionosphere storms. Since the North America-Europe transmission path is near the magnetic pole and auroral zone, where ionosphere storms have maximum effects, that path is thus markedly subject to ionosphere storms, even relatively slight ones which would have no effect on transmission over paths farther south. The effect occurs at high as well as broadcast frequencies and is so marked that it is commonly impossible to communicate directly, between North America and Europe during ionosphere storms and radio traffic is then actually carried on by relaying through Buenos Aires. As these conditions prevail for several days, the North America-Europe transmission path is almost never entirely free from ionospheric storminess. The prevalence of ionospheric storminess in the transmission path appears to present a complete explanation of the unsatisfactory transmission between North America and Europe.

AN AUTOMATIC WEATHER STATION.

Radio has made possible the collection of weather data from completely automatic stations installed at isolated locations, such as mountain peaks and small islands, which transmit meteorological information at predetermined intervals.

In the August *Journal of Research* (RP 1318), Harry Diamond and Wilbur S. Hinman, Jr., describe an automatic weather station which utilizes the same principle as the radio sonde. The variation in the meteorological element is converted into a change in resistance which in turn produces a change in modulation frequency. The essential difference lies in the use of much lower frequencies, 0.15 to 3.0 cycles per second. The low frequencies allow mechanical keying of a conventional radiotelegraph transmitter; complicated modulating equipment is, therefore, unnecessary. A manual counting method or simple electrical counters may be used at the receiving end for evaluating the observations. An experimental station of this type, installed at the Naval Air Station, Anacostia, D. C., on April 1, 1940, has since been in daily operation.

The experimental station includes a 15-watt radio transmitter with battery power supply; instruments for measuring pressure, temperature, humidity, wind direction and velocity, and rainfall; means for converting the instrument deflections into corresponding variable resistors; modulating equipment for keying the radio transmitter at a rate depending on the value of the particular variable resistor in circuit; automatic control equipment for connecting the instrument resistors into circuit in a definite sequence and for identifying the several observations by appropriate code letters; and a timing clock for starting the equipment at scheduled times.

The pressure, humidity, and rain gage instruments are of standard design, the rain gage being of the weighing type. In each instrument a relay-operated clamping bar is added for clamping the instrument pointer against the edge of a wire-wound resistor when an observation from that instrument is desired; this provides the means for converting the instrument deflection into a resistance variation. The instrument pointer is thus allowed to swing freely except when an observation is being transmitted.

The temperature element is a glass capillary tube filled with an electrolyte having a high temperature coefficient of electrical resistance; the resistance of this device is thus a function of the ambient temperature.

The wind direction indicator (of standard type) has eight contact segments corresponding to the eight principal compass points. A different fixed resistor is connected to each segment and thrown into circuit when the wind vane assumes that direction. Directions intermediate to any two principal directions are indicated by taking advantage of the oscillation of the wind vane about its average position; such oscillation tends to connect into circuit successively, on a proportional basis, the two resistors corresponding to the adjacent principal directions. The average value of the resultant keying frequency thus lies between the values for the two principal directions considered.

The wind velocity indicator is a standard commercial cup anemometer with the "take-off" contacts stepped up by a factor of four so that four contacts per minute correspond to one knot. These contacts are made to key the radio transmitter directly.

The automatic control equipment is arranged to allow a warm-up period for the transmitter after starting, next to send out the station call letters, a reference frequency, and finally the several observation frequencies corresponding too the desired measurements, each preceded by an identifying code. The sequence is repeated twice. Special cams provide that signals start at the beginning of the first sequence and do not stop before the end of the second sequence.

A month's automatic operation of the experimental station has shown the system to be reliable mechanically and electrically. The average errors obtained in the measurements without regard to sign were: Barometric pressure, 1.5 millibars; temperature, 0.5° C; relative humidity, 4 per cent; wind direction, none for the eight primary compass points with effective indication of intermediate points; wind velocity; less than one knot; rainfall, 0.02 inch (estimated).

The receiving equipment consists, in the simplest case, of an ordinary radio receiver, headphones, and stop-watch. Accordingly, the observations may be obtained by field crews; this is often an advantageous feature.

REMOVAL OF STATIC CHARGES FROM CHEMICAL GLASSWARE.

The static charge acquired by chemical glassware when wiped may cause a serious error in weighing the vessel, this difficulty being particularly pronounced during the winter months when the moisture content of the atmosphere is low.

For instance, in the Pregl method for the microchemical determination of carbon and hydrogen, the absorption tubes are wiped with a chamois. This causes a static charge that leaks off so slowly, when the humidity is low, that the time schedule (usually 10 to 15 minutes) between completing a combustion and weighing the absorption tubes can not be maintained.

F. W. Van Straten and W. F. Ehret state that the charge can be removed by the high-frequency discharge from a device commonly used to detect pinholes in evacuated apparatus.

Clement J. Rodden of the Bureau's Chemistry Division has found that if ultraviolet light is used to ionize the air surrounding a glass vessel the charge can readily be dissipated. In experiments at the Bureau, the vessel was wiped with a dry chamois and was considered to have reached constant weight when the variation was less than 0.05 mg. using a macrobalance. Weighings were made usually after 5-minute interval exposure to the light. In some instances this was reduced to 2-minutes. As a safe general rule, it is recommended that the wiped article be placed about 2 feet from either a Hanovia Alpine Sun Lamp or General Electric Lab-Arc, for 10 minutes.

SYNTHETIC RUBBER.

Synthetic rubber has now been used commercially for about 10 years. A summary of facts and figures on this subject is presented by Lawrence A. Wood in a new Bureau Circular, C427, entitled "Synthetic Rubbers: A Review of Their Compositions, Properties, and Uses." The paper also appeared in the July issue of the *India Rubber World*. The most active research has been carried on in Germany, Russia, and the United States. In the first two countries the primary aim seems to have been to duplicate, or nearly duplicate, the properties of natural rubber; in the United Staes, on the other hand, the apparent objective has been to produce a product superior to natural rubber in some respect, so as to justify, in a free market, the higher cost, which is in most cases at least three or four times that of natural rubber. Recent international events have somewhat changed the American viewpoint, but have not as yet had an influence on the development of synthetic rubber in this country.

The survey lists about thirty varieties of synthetic rubber, almost all of which are in present commercial production. The varieties are grouped in six general classes, according to chemical composition, and the discussion follows this classification. The classes are: (1) Chloroprene polymers, (2) butadiene polymers, including copolymers, (3) organic polysulphides, (4) isobutene polymers, (5) plasticized vinyl chloride polymers, and (6) dimethyl butadiene polymers. Familiar examples of each of these types are, respectively, (1) Neoprene, (2) the German Buna rubbers, (3) Thickol, (4) Vistanex, (5) Koroseal, and (6) "methyl rubber." Since the last type is chiefly of historical interest, it is treated only briefly. For each of the first five types, information is given concerning the raw materials used in production, the chemical reactions of manufacture, and the general conditions of polymerization. There is also some discussion of the compounding and vulcanization of the different types and of the properties and uses of the product.

Published values of the properties of the different varieties of synthetic rubber are summarized in comparative form, especially those properties which can be expressed by fundamental numerical values. Tables include published values of density, refractive index, identity period along the fiber axis, swelling in liquids, tensile strength, and permeabilities to water and to hydrogen. Values of dielectric constant, power factor and resistivity are also given. In Germany and Russia synthetic rubber is used to displace natural rubber in all its applications; in other countries, especially the United States, only those applications for which natural rubber is notably deficient have, so far, been of importance. Synthetic rubbers can be made to show great superiority to natural rubber in resistance to the effects of liquids, particularly petroleum products, and to deterioration by exposure to light, heat, ozone, and oxygen. A bibliography of over 200 references is given, listing scientific literature on this subject during the decade 1930–1940.

Orders for C427 should be sent to the Superintendent of Documents, Government Printing Office, Washington, D. C. The price is 10 cents.

THE FRANKLIN INSTITUTE

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon. 601 readers made use of the facilities during the twenty-six days of July.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

Observations on the Anticatalase Activity of Sulfanilamide and Related Compounds before and after Ultraviolet Irradiation.—MARJORIE P. BENOY. Sulfanilamide and a number of closely related compounds were found by Main, Shinn and Mellon (*Proc. Soc. Exptl. Biol. Med.*, **39**, 272, 1938) to have on catalase a definite inhibitory effect which was increased by preliminary exposure of the compounds in solution to ultraviolet light. Particular significance was attached by them to the intrinsic, catalase-depressing power of the unirradiated compounds and a possible connection between it and therapeutic potency was suggested. Subsequently these workers (Shinn, Main, and Mellon, Ibid., **42**, 736, 1939; Locke and Mellon, *Science*, **90**, 231, 1939) postulated that *p*-hydroxamino benzenesulfonamide was the compound developed by ultraviolet light which was responsible for the *in vitro* enzyme-inhibiting action of the irradiated solutions.

The observations made in this laboratory on the native and ultraviolet light-induced, anticatalase activity of sulfanilamide and related compounds, and the conclusions derived therefrom, are somewhat at variance with those of the authors mentioned above.

Materials.—Catalase was prepared from rabbit red blood corpuscles by the method of Sevag and Maiweg (*Biochem. Z.*, **288**, 41, 1936).

Aromatic Chemicals were in general obtained on the market and used without further purification. Sulfamethylthiazol (2-sulfanilamide-4-methyl thiazole) was courteously supplied by the Maltbie Chemical Company. *p*-Nitrobenzenesulfonamide was prepared by Mr. Harry Winter of this laboratory from *p*-nitrobenzenesulfonylchloride made by an adaptation of the Loudon-Shulman method (*J. Chem. Soc.*, 1938, p. 1618). Benzene "A" was prepared from Mallinckrodt's "benzol pure" by the usual procedure for the removal of thiophene, followed by fractional distillation. Benzene "B" was Baker's c.p. thiophene-free benzol used without treatment. Benzene "C" was made by the distillation of benzoic acid with soda-lime.

Procedure.—Aqueous solutions of the chemicals were irradiated in 25 cc. portions in open Petri dishes placed 11 inches from the arc, the dishes being gently agitated during exposure. A Cooper Hewitt horizontal Uviarc laboratory outfit, code number DC 6H4D1, 100 volts, was used without filter. The time of irradiation varied with the different compounds studied, and was in each case that interval not exceeding 10 minutes which had been found experimentally to give a maximum effect.

All reactions between catalase and substrate were carried out at 0° C., and the enzyme always stood in the presence of the test solution half an hour before the addition of peroxide. A mixture of 25 cc. of 0.067 M phosphate buffer, pH 7.0, 10 cc. of the aqueous test solution (irradiated or unirradiated), and 5 cc. of the enzyme preparation in 0.067 M phosphate buffer, was prepared; after 30 minutes in the ice bath, 10 cc. of 0.06 M H_2O_2 were added, and at intervals of 5, 10, and 15 minutes thereafter, 10 cc. portions were withdrawn and the unused H_2O_2 estimated iodometrically. Controls and blanks were carried along with the experimental mixtures. The concentration of the enzyme solution was always such that the addition of 5 cc. to the control would result in the destruction of about one-half of the peroxide in 15 minutes.

Results.—In Table I are presented data showing the activity of catalase in the experimental mixtures, expressed as percentage of the activity of the corresponding controls. The activity is measured in terms of the velocity constant k appearing in the equation $k = 1/t \cdot \ln a/(a - x)$, where a is the initial H_2O_2 concentration and $a - x$ the concentration at time t.

No unmistakable depressing effect was observed in the case of any unirradiated compound. On the other hand, all of the substances tested, except p-nitrobenzene sulfonamide, showed clearly-defined, enzyme-inhibiting power following the exposure of their solutions to ultraviolet irradiation.

Among the compounds investigated were three which represent the stepwise degradation of the sulfanilamide molecule

TABLE I.

Catalase Activity.

	In unirradiated solutions of molar concentrations:				In irradiated solutions of molar concentrations:					
	10^{-2}	10^{-3}	10^{-4}	10^{-6}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-8}
Sulfanilamide		97	101		18		35		67	91
Sulfapyridine			98				68		79	
Sulfamethylthiazol				100				72	82	
Sodium sulfanilyl sulfanilate	95	97					70		74	
p-Nitrobenzene sulfonamide		105*	103*				94	98		
Benzene sulfonamide		101				62	57	80		
Sodium benzenesulfonate		101**		101**		74	79	82	92	
Benzene A		97*				66*				
Benzene B		96*				76				
Benzene C						68				

Note: The reaction period between enzyme and substrate was 5 minutes except in those cases marked * where it was 30 minutes, and in those marked ** where it was 10 min.

—benzenesulfonamide, sodium benzenesulfonate and benzene; these substances proved to be very nearly as susceptible to ultraviolet stimulation in this respect as sulfanilamide. In order to be sure that this unexpected effect produced on benzene was not due to impurities, specimens of the hydrocarbon from three different sources were studied with nearly identical results. Since these three compounds are structurally incapable of giving rise to *p*-hydroxamino derivatives, the probability of *p*-hydroxaminobenzenesulfonamide being the specific, active agent in irradiated solutions of sulfanilamide is brought into question. These observations suggest on the other hand that it is the benzene ring itself which carries the ability to be light-stimulated to anticatalase activity. An attempt was made to synthesize *p*-hydroxamino benzenesulfonamide; but inasmuch as the identity of the product could not be definitely established, no report on its behavior with the enzyme is justified.

A few experiments with sulfanilamide solutions irradiated while N_2 or O_2 was being passed through the solutions showed that although the presence of O_2 was necessary for the production of a purple color, it was not essential for the development of the antienzyme property, N_2-saturated solutions becoming very nearly as active as those treated with oxygen.

Summary.—None of the compounds studied (sulfanilamide, sulfapyridine, sulfamethylthiazol, sodium sulfanilyl sulfanilate, *p*-nitrobenzene sulfonamide, benzene sulfonamide and benzene) showed anticatalase activity at 0° C. before ultraviolet irradiation, while all except *p*-nitrobenzene sulfonamide were definitely active after exposure to light. It is suggested that such compounds became activated by some direct attack upon the benzene ring rather than by the formation of *p*-hydroxamino derivatives.

The Molecular Basis of Resin Behavior.—ELMER O. KRAEMER. (Condensation of paper presented at Gibson Island Conference on Organic High Molecular Weight Compounds, June 8, 1940. In this paper, a critical survey covering what is known about the chemical constitution and molecular size, homogeneity, and shape of organic macromolecules was presented, with particular emphasis on the limitations in present knowledge and the approximations in conventional conceptions.)

Chemical Structure of Organic Macromolecules.—The simplest conceivable type of macromolecule is the primary-valence chain of identical atoms or identical radicals, terminated on each end by a univalent end-group. Much of the literature on the subject conveys the impression that most macromolecules are of this simple type, whereas as a matter of fact, it is not positively known that any real macromolecule corresponds strictly to the idealized form. It is possible that certain polyesters, prepared under carefully controlled conditions from especially pure reactants, do approximate quite closely to the ideal linear macromolecule, although Staudinger is apparently doubtful. Usually, however, the nominally simple linear macromolecules contain definitely detectable quantities of atoms or groups that are not represented in the idealized chemical formula, or depart from the linear chain form by virtue of branches, cross-links, rings and other geometrical deviations.

Thus, probably all vinyl derivative polymers resulting from any kind of unsaturated monomers are more or less branched, and probably all of them contain traces of radicals or atoms other than those shown by the conventional formulation owing to the incorporation of impurities, including catalysts, or to side reactions. Staudinger admits in his latest papers that the structures of most of the synthetic vinyl polymers are unknown. The marked effect of small amounts of impurities is strikingly shown by Staudinger's observation that 0.002% of divinyl benzene in styrene results in an insoluble polystyrene.

Rubber is also commonly considered a simple linear macromolecule, although this conception is incompatible with the difference between gel rubber and sol rubber and the conversion of the former to the latter by exposure to oxygen. It is also inconsistent with the fact that oxygen-free latex rubber yields no diffusion rubber upon extraction with petroleum ether. Apparently the native latex particles are covered with an insoluble rubber derivative or with cross-linked, perhaps "two-dimensional" rubber molecules. Processed rubber always contains combined oxygen and probably also cyclic residues, neither of which appears in the formula for polyisoprene. Similarly, synthetic "rubbers" containing an unsaturated polymer unit probably normally contain bound oxygen and are more or less cross-linked or "self-vulcanized," besides having the branched structure characteristic of vinyl polymers.

Even cellulose and cellulose derivatives may not correspond entirely to the ideal linear type, as commonly assumed. It is generally known that cellulose contains carboxyls, which are certainly not end-groups, and in addition, cellulose may contain ester groups in the chain, which, according to Staudinger, would account for the anomalously high viscosities of certain nitrates, compared to that of the corresponding cuprammonium solutions of the initial celluloses. It is furthermore questionable whether cellulose esters, prepared by reactions with mixed acids, are ever entirely free of ester groups arising from the "catalyst" acid. With regard to the geometrical form of the cellulose skeleton, Haworth finds that cellulose may be methylated to give degraded products, which nevertheless contain no detectable quantity of tetramethyl glucose end-groups, and he has suggested that certain celluloses and their derivatives have a ring structure. For the present, it will suffice merely to mention the small content of pentoses and hexoses other than glucose in cellulosic materials, and the cross-links, whatever they may be, which are responsible for the insolubility of native cellulose and of Berl's special nitrates.

It is believed that careful examination of all the presumably simple linear macromolecules will show that they depart from the ideal type with respect either to their chemical composition or to their geometrical form. Although the deviation from ideality often is small, it is commonly surprising to the academic investigator how frequently these small differences are of great practical importance, e.g., in connection with properties such as solubility, water-sensitivity, light- and heat-stability, gelation-tendencies, viscosity, and mechanical behavior. In fact, it often seems that macromolecules are more sensitive to traces of unexpected radicals or stereochemical arrangements than ordinary molecules are to impurities.

A second geometrically simple type of macromolecule is the globular one, to which belong many of the native crystallizable proteins. Chemically, on the other hand, these macromolecules are very complicated, for they typically contain a dozen or two different amino-acids (as the polymeric unit), besides, commonly, a certain amount of carbohydrate, phosphoric acid, vitamins, or various prosthetic groups. Certain other macromolecules, e.g., glycogen, appear to be geometrically globular, but they must be distinguished from the globular proteins in that the latter can not be degraded into polymeric homologous series of products of globular form. Glycogen probably therefore belongs with starch and various other polysaccharides in being more or less highly branched in structure.

A third type of macromolecule is the three-dimensional molecule, potentially indefinite in extent, which results from the interaction of substances in some of which there are three or more reacting functional groups. To this class belong the alkyd and phenolic resins and their analogs, vulcanized rubber and "synthetic rubbers," linoxyn, probably coal, and the like. In each instance the macromolecule may be conceived as an assembly of primary-valence chains cross-linked to a greater or lesser degree by bivalent atoms or radicals. Except when they are relatively small (e.g., less than 5000 in weight), these molecules are normally insoluble, in contrast to the globular proteins, which in a purely geometrical sense are also three-dimensional. The essential difference is that a very high molecular-weight globular protein has a well-defined shape and surface, whereas correspondingly large synthetic three-dimensional molecules normally are highly irregular in form, lack a definable surface, and are formed under conditions permitting permanent intertangling.

Determination of the Molecular Weights of Macromolecules.—It must in the first place be admitted that there are no absolute methods for determining the molecular weight of material in the solid state or in the fused state. In fact, all absolute methods involve the properties of solutions. As a consequence, there is no trustworthy information concerning the molecular sizes of the insoluble, infusible macromolecular materials. Since fusible macromolecules are also soluble, at least above the melting point, they may be in principle investigated by absolute methods.

The determination of molecular size involves two steps: (1) the determination of the size of the individual units or particles of the material in the dissolved state, and (2) the demonstration that these units are single molecules. With respect to the first step, there are, for macromolecules, only three generally applicable methods capable of giving absolute values, and these three methods are closely related theoretically, being all based upon the laws of dilute solutions. They are (*a*) osmotic pressure, (*b*) sedimentation equilibrium in the ultracentrifuge, and (*c*) combination of sedimentation velocity (determined with the ultracentrifuge) and diffusion constant. (For detailed discussion of methods (*b*) and (*c*), see Svedberg and Pedersen, "The Ultracentrifuge," Oxford Press, 1940.)

For the purposes of the Conference, it is unnecessary to discuss theoretical and experimental details, but to bring out the limitations of our knowledge in this field, it is preferable to focus attention onto the difficulties encountered in the application of these methods. Osmotic pressure gives no information concerning the uniformity in molecular weight, although such information is essential since practically all macromolecular materials are markedly non-uniform; ultracentrifugal methods on the other hand give quantitative measurements of heterogeneity. Both osmotic pressure (avoiding dynamic methods, which may lead to erroneous results because of non-uniformity in concentration near the membrane and in the body of the solution) and sedimentation equilibrium are quite slow, requiring from several days to several weeks for the attainment of equilibrium, and the macromolecules must accordingly be stable if reliable results are to be obtained. For solutions such as cellulose in cuprammonium, it is difficult to insure this. For this particular solution, as well as certain others, it is difficult to find suitable membranes for osmotic pressure measurements. Furthermore, membranes commonly used often show detectable permeability for moderately small molecules, e.g., in the range 10,000–20,000. In all three methods, combination of the solute with components of the solvent may lead to errors, which may be serious in ultracentrifuge methods when mixed solvents containing components differing greatly in specific volume are used (see the author's notes, J. FRANK. INST., **229**: 393, 531, 680, Mar., Apr., May, 1940). Coulomb forces arising with macromolecular ions must be taken into account in all three methods. For proteins, it is usually sufficient to mask these forces by the addition of an excess of a neutral salt. However, for more strongly acidic or basic materials, such as polyuronic acids, polyacrylic acids, chitosan, etc., it is difficult or impossible to neutralize the coulomb forces without aggregating or salting out the macromolecules. Difficulties are also experienced with all three methods when applied to materials with very large, highly extended molecules, as manifested by large intrinsic viscosities, in that satisfactory experimental values can not be obtained at concentrations low enough to eliminate molecular interference and interaction. One then faces the problem of satisfactorily extrapolating to zero concentration; in such instances, sedimentation equilibrium gives the most reliable results.

These three methods have been applied to a large variety of macromolecular products. Careful systematic work with the osmotic pressure method has been done on the proteins by Sørensen, Adair, Burk and others, and in earlier years, isolated researches were carried out by a great many different workers on rubber, cellulose derivatives, starch, gums, etc. During the last decade more intensive work with the non-proteins has been done by Dobry, and the students and co-workers of Herzog, Staudinger, Haworth and Meyer. Most of the ultracentrifuge work has been done in Svedberg's laboratory, principally on proteins, although cellulose starch, pectin, glycogen, and various plant-juice carbohydrates, polystyrene, methyl cellulose and cellulose acetate have also been investigated, the last three by Signer and his collaborators. The author and his co-workers made the first investigation of a synthetic high polymer with the ultracentrifuge (polyhydroxydecanoic acid) and have also investigated cellulose and cellulose derivatives in some detail and rubber and polychloroprene more briefly. The ultracentrifugal investigations carried out at Lister Institute, Oxford, the University of Wisconsin, Rockefeller Institute, Harvard, and Yale have been largely limited to proteins. For additional details regarding results, see Svedberg and Pedersen, "The Ultracentrifuge."

(*To be continued.*)

BOOK REVIEWS.

CLASSICAL AND MODERN PHYSICS, A DESCRIPTIVE INTRODUCTION, by Harvey E. White. 712 pages, illustrations, plates, 16 × 24 cms. New York, D. Van Nostrand Company, Inc., 1940. Price $3.75.

Popularity in the physical sciences has no doubt been the result of the recent advances in knowledge and the opening of very promising fields. It is a healthy and gratifying condition to see the rise of popularity, both for the purpose of furthering the advance of knowledge and to have a speaking acquaintance with the present status of the subject so as to evaluate developments. Today, one can hardly be said to have a broad education unless there is included an understanding of the fundamentals of physics. Teachers and authors have recognized this fact and there are books available of almost every degree of preliminary requirement. The book at hand is one of them, a recent one. It is a text which gives an elementary treatment of the principles of classical physics with a comprehensive treatment or survey of modern physics and atomic structure.

The introduction contains a brief discussion with examples of some optical illusions, a catchy, interesting and informative coverage which is characteristic of the whole book. It is given in this place as an illustration of false impressions so easily arrived at from the use of subjective methods of observation in contrast to the objective methods of physics. The entertainment feature of this creates a desire to start the book in earnest.

The coverage of subjects is in the usual order—mechanics, properties of matter, heat, sound, electricity and magnetism, and light. Then there follows discharges through gases, the quantum theory and atomic structure, atomic and nuclear processes, and finally astrophysics.

The main feature of the book is that it is written almost entirely in an explanatory manner not unlike conversation. The method of approach and presentation is such that a student with the simplest principles of algebra and plane geometry should have no difficulty in following. In most cases the presentation of each new subject includes: first, a brief historical account of the discovery; second, an experimental demonstration of the phenomenon; third, a discussion of practical applications accompanied by one or more experiments; and fourth, a brief account of the accepted theory and its experimental confirmation.

The book is well illustrated; there are many simple formulas and tables, and a subject index. Nothing was spared in making this book an attractive and interesting treatment.

R. H. OPPERMANN.

LABORATORY MANUAL OF PHYSICS, by Clinton Maury Kilby. Second Edition, 146 pages, illustrations, 14 × 22 cms. New York, D. Van Nostrand Company, Inc., Price $1.75.

One of the first things a student of physics must learn is to observe objectively. Therefore it is of utmost importance that elementary laboratory instruction be undertaken with care. This little book contains a description of some seventy-three experiments which can be used in such work. For the most part they can be performed with inexpensive apparatus and are so designed as to inculcate the simple principles of mechanics, the properties of materials, heat, electricity, magnetism and light. The object, apparatus needed, a brief statement of theory, and the method of performing each experiment are given.

R. H. OPPERMANN.

ELEMENTS OF ELECTRO-MAGNETIC THEORY, by A. Wilmer Duff and Samuel J. Plimpton. 173 pages, illustrations, 15 × 22 cms. Philadelphia, The Blakiston Company. Price $2.75.

This is a text designed to fit into a particular place in undergraduate curriculum of general science and engineering. As such it is restricted to topics of an intermediate mathematical nature and yet avoids to a considerable extent the coverage ordinarily given in electrical engineering classes. The book should therefore have appeal to the serious minded electrical engineering student from the standpoint of design.

The Chapters begin with Coulomb's Law and Gauss's Theorem and proceed first through electrical subjects such as electric potential with a very good definition of its meaning, a discussion of the characteristics of groups of charges, dielectrics, Faraday's Graphical Method to state the properties of an electric field, the method of conjugate functions, etc. Subjects on magnetism are then taken up including magnetic media where it is forcibly pointed out that the conditions here are somewhat more complex than in the electric field, and the processes of magnetisation in the various classes of substances. Up to this point electricity and magnetism are treated as separate entities and a treatment under the heading of magnetic fields of currents begins the connection between them with an account of Ampere's Electromagnetic Theory. Subsequently electromagnetic induction, alternating currents, Maxwell's equations for metallic media and with displacement currents, electromagnetic waves, and properties of moving charges, complete the book.

The topics are arranged in the historical order of the discovery and development of principles. At the end of each Chapter there are carefully selected exercises and the book contains many drawings as illustrations at appropriate points. A subject index appears in the back. Based on the thought that electrostatics is the foundation for all parts of the subject, this book contains much of helpful interest to the electrical engineer.

R. H. OPPERMANN.